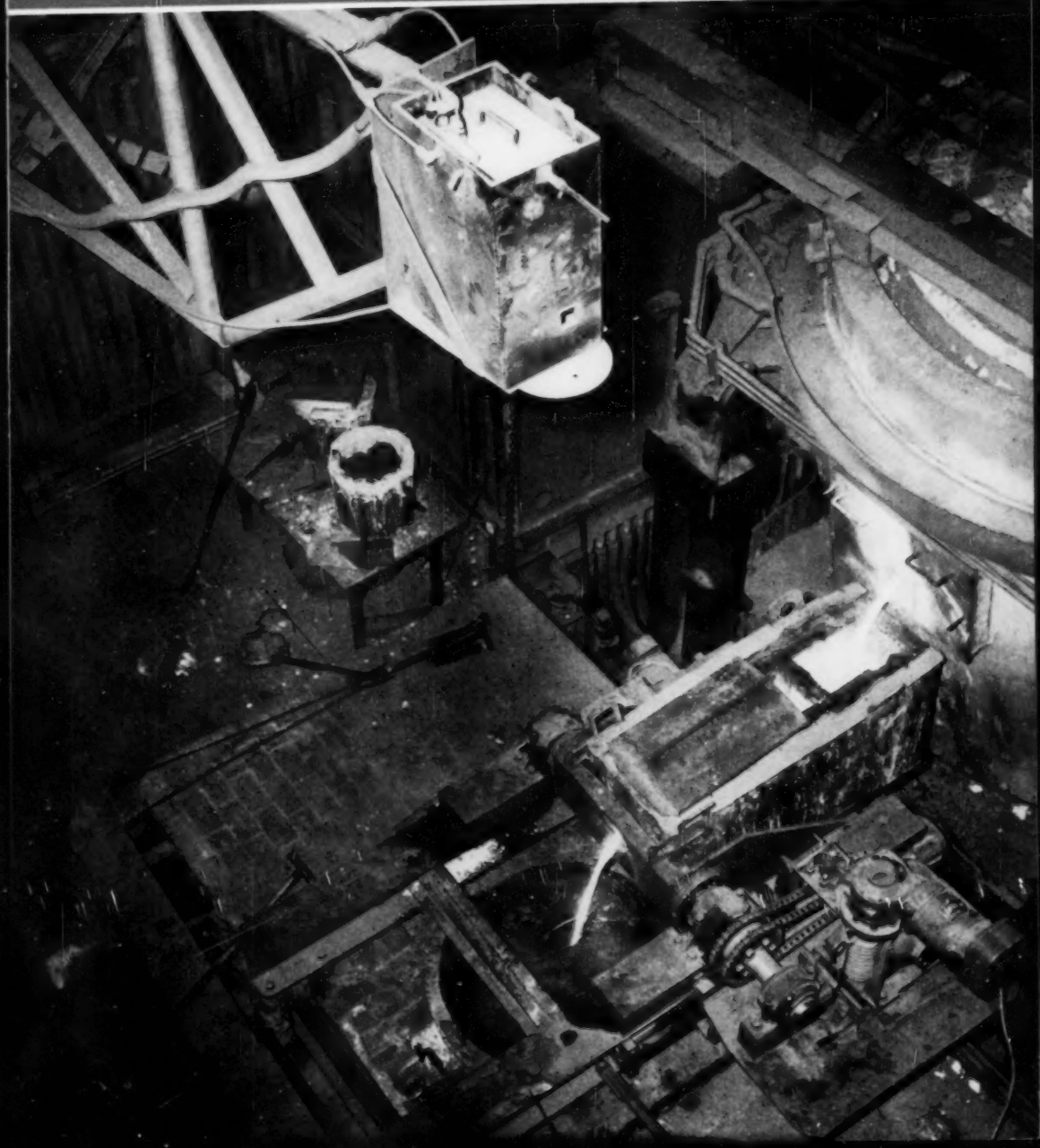
MARCH, 1951

Journal of METALS



IT'S "LOADED" WITH BETTER TELEPHONE SERVICE

Twenty of the Bell System's newest small loading coils—like the one at the left—are housed in the long black case, mounted in a cable splice. This type of installation permits the economical extension of city cables to serve out-of-town subscribers.

Many more wires can be crowded into a cable sheath when the wires are fine. But normally, wires don't transmit as well when they are fine and closely packed.

Bell engineers long ago learned to make wires do better work by loading them with inductance coils at regular intervals. The coils improve transmission and let messages travel farther. But originally the coils themselves were large, heavy and expensive. The cases to hold them were cumbersome and costly too.

So year after year Bell scientists squeezed the size out of coils. To make magnetic cores of high permeability they developed Permalloy. Tough but extra-thin insulation permitted more turns to a core.

New winding machines were developed by the Western Electric Company. Coil size shrunk to one-fiftieth. Some—like the one shown above—can be mounted right in cables themselves.

The 15,000,000 coils in the Bell System today mean thinner wires, more wires in a cable—more economical service for you. They demonstrate once more how Bell Telephone Laboratories work continually to add to your telephone's value.

BELL TELEPHONE LABORATORIES

WORKING CONTINUALLY TO KEEP YOUR TELEPHONE SERVICE BIG IN VALUE AND LOW IN COST

Journal of METALS

VOL. 3, NO. 3 — MARCH, 1951

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the metals industry by the

Metals Branch

American Institute of Mining and Metallurgical Engineers, Inc.
29 West 39th Street, New York 18

• • •

THOMAS E. LLOYD
Manager of Publications
Editor, Journal of Metals

• • •

H. N. UNDERHILL — A. S. COHAN
Associate Editors

D. G. GARRETT — MARGARET BAGG
Assistant Editors

GRACE PUGSLEY — Production Manager

W. J. SEWING — Asst. Prod. Mgr.

• • •

METALS BRANCH COUNCIL

C. C. Long — Chairman
E. O. Kirkendall — Secretary
R. M. Brick — IMD Chairman
T. L. Joseph — ISD Chairman
O. C. Ralston — EMD Chairman
M. Gensamer — D. S. Eppelsheimer
H. K. Work — R. J. Lund

TECHNICAL PUBLICATIONS COMMITTEE

F. B. Foley — Chairman
E. J. Kennedy, Jr. — Secretary

AUXILIARY PUBLICATIONS COMMITTEE CHAIRMEN

F. N. Rhines — Institute of Metals Div.
F. M. Washburn — Iron & Steel Div.
Philip T. Stroup — Extract. Metal Div.

• • •

JAMES A. STANGARONE
Advertising Manager

• • •

The AIME Publishes:

Journal of Metals
Mining Engineering
Journal of Petroleum Technology

COVER

Continuous casting of steel as carried out at Babcock & Wilcox Tube Co., Beaver Falls, Pa. Molten steel from an electric furnace can be seen being poured into a tun-dish, from whence it flows into a brass mold that is about 56 in. high. Pouring rate into the mold is controlled by an X-ray device, and the whole operation is observed by television (camera above left). See article p. 223.

FEATURES AND NEWS

Journal of Metals REPORTER	213	Coming Events	203
"Drift of Things"	214	News of Industry	215
Personnel Service	208	Short Cuts	206
Meet the Authors	202	N.E. Regional Meeting	262
New Products	204	Personals	264
		National Blast Furnace, Open Hearth Programs	261

TECHNICAL ARTICLES

New Machining Method	Alvin S. Cohan	216
Redesigning a Secondary Smelting Plant	Earl R. Marble, Jr.	218
Continuous Casting of Steel at Babcock & Wilcox Tube Co.	Isaac Harter, Jr.	223
Some Observations on the Continuous Casting of Steel	Irving Rossi	227

TRANSACTIONS

El Paso Refinery of Phelps Dodge Refining Corp.	B. B. Kunkle	229
Sulphur Activities in Liquid Copper Sulphides	R. Schuhmann, Jr., O. W. Miles	235
Microscopic Observation of the Solidification of Cu-Ni Alloy Droplets	R. E. Cech, D. Turnbull	242
Solubility of Hydrogen in Molten Lead	W. R. Opie, N. J. Grant	244
Intergranular Energy of Fe and Some Fe Alloys	L. H. Van Vlack	251

TECHNICAL NOTES

Surface Diffusion in Sintering of Spheres on Planes	P. Schwed	245
Re-Solution of Precipitated Silver in Cu-Ag Alloys	H. Margolin, W. R. Hibbard, Jr.	247
Fractographic Pattern of 475°C Embrittlement in Stainless Steel	C. A. Zapffe	247
Structure of Spherulites in Nodular Cast Iron	H. E. Stauss, F. W. Von Batchelder, E. I. Salkovitz	249
Deformation and Recrystallization Texture of Cold-Drawn OFHC Cu Wire	W. A. Backofen	250
Precipitation and Diffuse Scattering in an Fe-Mo-Co Alloy	A. H. Geisler, F. E. Steigert	259

To conform with Postal Regulations, a change had to be made in the method of numbering the volumes of Journal of Metals, beginning with the March, 1951 issue. This issue will be numbered Vol. 3, No. 3; and numbering will be consecutive thereafter. The AIME Transactions, Metals Branch, in a bound volume, will be numbered separately from the Journal.

Published the first day of each month by the American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $8 per year for non-AIME members in United States and North, South and Central America; $9, foreign; $6 for AIME members, or $4 in combination with a subscription to "Mining Engineering" or the "Journal of Petroleum Technology". Single copies, 75 cents; special issues, $1.50 . . .

The AIME is not responsible for any statement made or opinion expressed in its publications. . . . Copyright 1951 by the American Institute of Mining and Metallurgical Engineers, Inc. . . .

Registered cable address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index and Chemical Abstracts . . . Reentered as second-class matter Sept. 21, 1949, at the post office at New York, N. Y., under the Act of March 3, 1879. Additional entry established at Manchester, N. H.

FOREMOST IN
SCIENTIFIC DEVELOPMENT

IN THE REALM OF FORGING DESIGN AND THE DEVELOPMENT OF PROPER GRAIN-FLOW, WYMAN-GORDON HAS ORIGINATED MANY FORGING DESIGNS WHICH AT THE TIME OF THEIR DEVELOPMENT WERE CONSIDERED IMPOSSIBLE TO PRODUCE BY FORGING.

WYMAN-GORDON

ESTABLISHED 1883

FORGINGS OF ALUMINUM • MAGNESIUM • STEEL

WORCESTER, MASSACHUSETTS

HARVEY, ILLINOIS DETROIT, MICHIGAN

ZIRCONIUM METAL

in the form of

Sponge and Briquettes

with the following analysis

Zirconium	98.8 (by difference)	to 99.6%
Oxygen	0.1 (estimated)	to 0.2%
Nitrogen	.02	to .10%
Iron	.2	to .8%
Chromium	.02	to .10%
Nickel	.01	to .02%
Silicon	.02	to .10%

Write our New York Office for detailed information. 3½" diameter briquettes are furnished from ½" to 3" in height with bulk density of 160 to 190 lbs. per cu. ft. The sponge will be ¾" and down with a maximum of 15% through a 10 mesh screen.

TAM PRODUCTS

Registered U. S. Pat. Off.

TITANIUM ALLOY MFG. DIVISION
NATIONAL LEAD COMPANY

Executive and Sales Office: 111 BROADWAY, NEW YORK CITY · General Offices, Works, and Research Laboratories: NIAGARA FALLS, N. Y.

Carilloy "T" Steel greatly

ON THE MARION 5561 — WORLD'S LARGEST POWER SHOVEL

THE mammoth 45 cubic yard bucket on Hanna's "Groundhog" is moving more than a million yards of overburden every month. Despite the exceptional punishment it receives, the U·S·S CARILLOY T-Steel lip-plate has already been in service much longer than any steel previously used.

Further, the higher physical properties of T-Steel have made possible design changes which are now under way and which should greatly extend lip life beyond present construction.

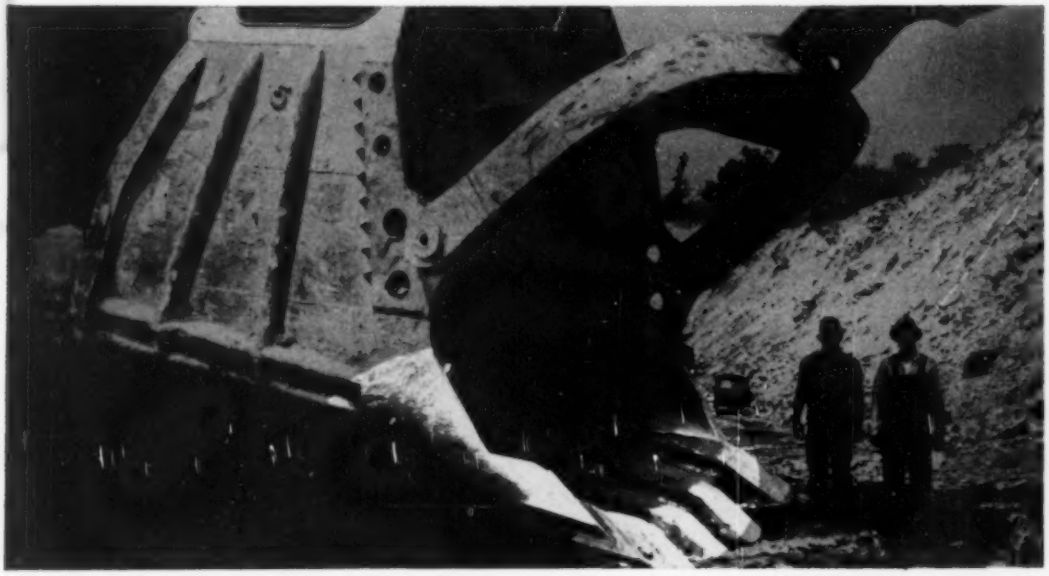
Here's what Hanna Coal Company says, as owner and operator, "The lip of this bucket (made from 4½" CARILLOY T-Steel) is one of the most critical sections and it takes a great deal of punishment when loading the rock strata we have at this location. At Marion Power Shovel Co., we have a *50-yard* bucket on order. It will be built almost entirely of T-Steel . . ."

In this new bucket, CARILLOY T-Steel will increase capacity 5 yards — almost *9 tons* — by cutting weight without any sacrifice in strength. And because it can be welded *in the field*, T-Steel construction makes it unnecessary to shut the shovel down for the many hours formerly required for shop repairs.

CARILLOY T-Steel, a product of United States Steel research, is a *low carbon* alloy steel, heat-treated with great precision. Minimum yield strength is 100,000 psi (for plates ¼" to 2" inc.) Furthermore, T-Steel will remain ductile at arctic temperatures—*even after welding*.

Welding does not lower the strength of the plate. If AWS electrodes E-12015 or E-12016 are used, welds remain 100% strong . . . both butt and fillet-welded specimens will break completely outside of the heat-affected area. As for toughness, laboratory tests have proved that, even after gas-cutting, T-Steel can be bent at more than 100°F. below zero.

CARILLOY T-Steel is normally produced in the forms of plates and bars. Nominal hardness is 250 Brinell, although 321 minimum Brinell can be furnished for abrasive conditions where a combination of high hardness, toughness and weldability is essential.



increases lip-plate life

MECHANICAL PROPERTIES—U·S·S Carilloy T-1 Steel Plates can be furnished Heat Treated to the following mechanical properties:

	Thickness ¼" to 2" incl.	Thickness Over 2" to 4" incl.	Thickness Over 4" to 6" incl.
Yield Strength, .2% Offset (min.)	100,000 psi	90,000 psi	90,000 psi
Tensile Strength (min.)	115,000 psi	105,000 psi	105,000 psi
Elongation in 2", % (min.)	18	17	16
Reduction of Area, % (min.)	55	50	45
	Thickness ¼" to ½" incl.	Thickness Over ½" to 1" incl.	Thickness Over 1" to 2" incl.
Cold Bend	180°D=1t	180°D=2t	180°D=3t

(Testing in accord with A.S.T.M. recommended practices.)

UNITED STATES STEEL COMPANY, PITTSBURGH

COLUMBIA STEEL COMPANY, SAN FRANCISCO • TENNESSEE COAL, IRON & RAILROAD COMPANY, BIRMINGHAM

UNITED STATES STEEL SUPPLY COMPANY, WAREHOUSE DISTRIBUTORS, COAST-TO-COAST • UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS **Carilloy Steels**

ELECTRIC FURNACE OR OPEN HEARTH • COMPLETE PRODUCTION FACILITIES IN CHICAGO AND PITTSBURGH

UNITED STATES STEEL

PROFESSIONAL SERVICES

Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $40 per year per inch.

ENGINEERS
METALLURGISTS
CONSULTANTS
Small Jobs Welcomed
SAM TOUR & CO., INC.
Laboratories and offices
44 Trinity Place
New York 6, N. Y.
Testing—Certifying
American Standards
Testing Bureau, Inc.

MAX STERN
Consulting Engineer
Expert for Scrap Recovery and Shipwrecking — Modernization of Plants and Yards for Ferrous and Nonferrous Metal Scrap
150 Broadway New York 7, N. Y.

LEWIS B. LINDEMUTH
Consulting Engineer
140 CEDAR STREET, NEW YORK 6, N. Y.
STEEL PRODUCTION
DESIGN · OPERATION · CONSTRUCTION · METALLURGY

Frank B. Foster, Inc.
INDUSTRIAL PLANTS
ROLLING MILLS
2217 Oliver Building
Pittsburgh 22, Pennsylvania

R. S. DEAN LABORATORIES, INC.
Consulting, Research Development Chemistry, Electrochemistry, & Metallurgy Laboratory Research on a Contract Basis
5810—47TH AVENUE AP-2821
RIVERDALE, MD.

Meet The Authors

E. R. Marble, Jr. (p. 218) attended Tufts College and MIT, receiving B.S. and M.S. degrees. Since 1942 he has served with American Smelting & Refining Co. at Garfield, Utah; U.S. Navy; and is now assistant to manager of technical operations at Federated Metals Div., A.S. & R. This AIME member likes hunting, fishing, and photography.

B. B. KUNKLE

B. B. Kunkle (p. 229) graduated from the Colorado School of Mines as a Petroleum Engineer, and worked for several petroleum and mining companies. Since 1942, he has been associated with Phelps Dodge Refining Corp., El Paso, Texas, where he is plant metallurgist. He is a member of AIME, and likes record collecting and tape recording.

R. E. Cech (p. 242) received his B.S. degree in Metallurgy from University of Wisconsin in 1948, and is a member of Tau Beta Pi. He is employed in the chemical metallurgy div. of General Electric Research Lab, Schenectady, N. Y., and belongs to AIME and ASM. His hobbies are carpentry and chinchilla ranching.

R. E. CECH

P. Schwed (p. 245) studied at University of Cincinnati for his B.A. and Ph.D. degrees. He is an aeronautical research scientist at NACA Lewis Flight Propulsion Lab., Cleveland, and has previously been employed by Schenley Laboratories, and University of Cincinnati. A member of American Physical Society and Electron Microscope Society, he enjoys photography.

Carl A. Zapffe (p. 247) has attended University of Minnesota, Michigan College of Mining & Technology, Lehigh University, and Harvard University, receiving B.S., M.S., and Sc.D. degrees. He has been associated with Du Pont Experimental Station, Battelle Memorial Institute, and Rustless Iron & Steel Corp., and since 1946 has been self-employed as a consultant in Baltimore, Md. This rather busy person has received numerous awards and prizes, is a member of AIME and almost two dozen other professional societies, and is the author of four books and more than 100 papers.

CARL ZAPFFE

H. E. Stauss (p. 249) received A.B. and Ph.D. degrees from Washington University (St. Louis) and University of California. He has been associated with Baker & Co., Inc., was chief of the precious metals and mercury section of the miscellaneous minerals div. of the WPB from 1942 to 1945, and is now head of the electric and magnetic alloys branch and acting associate superintendent of the metallurgy div., Naval Research Lab. A member of AIME, American Physical Society, and ASM, his hobby is gardening.

F. W. Von Batchelder (p. 249) studied at Michigan College of Mining & Technology for his B.S. and M.S. degrees. He has previously been employed by Michigan Alkali Co., Great Lakes Steel, Navy Dept., and is now physicist for Naval Research Lab, Washington, D. C. He belongs to American Crystallographic Assoc., and SNDT, while for relaxation he likes photography, target shooting and water sports.

E. I. SALKOVITZ

E. I. Salkovitz (p. 249) attended Carnegie Institute of Technology, and received B.S., M.S. and D.Sc. degrees in Physics. Before his association as physicist for metallurgy div., Naval Research Lab, he was employed by Bacharach Industrial Instrument Co., and Research Lab. of American Society of Heating & Ventilating Engineers. Hiking and music are the hobbies of this AIME student associate.

L. H. Van Vlack (p. 251) was awarded B.S. and Ph.D. degrees by Iowa State College and University of Chicago. He has been petrographer for Carnegie-Illinois Steel Corp. (now U.S. Steel Co.) since 1942, except for leaves for military service and graduate study. In addition to his hobbies of reading and hiking, he belongs to AIME, ASM, American Ceramic Society, and Mineralogical Society.

L. H. VAN VLACK

Coming Events

Mar. 2, AIME, San Francisco Section, joint meeting with Auxiliary, Sir Francis Drake Hotel, San Francisco.

Mar. 5, AIME, Florida Section, Lakeland, Fla.

Mar. 5, AIME, Mexico Section, American Club, Mexico City.

Mar. 5-9, ASTM, spring meeting and committee week, Cincinnati.

Mar. 6, Society for Applied Spectroscopy, 6 pm dinner, Tosca's; 8 pm meeting, Socony-Vacuum Training Center, New York.

Mar. 11-14, American Institute of Chemical Engineers, regional meeting, Greenbrier, White Sulphur Springs, Va.

Mar. 13-16, National Assn. of Corrosion Engineers, 1951 conference and exhibition, Hotel Statler, New York.

Mar. 19-23, Conference on Industrial Personnel, Dept. of Industrial Engineering, Columbia University, New York, N. Y.

Mar. 19-23, Western Metal Congress and Exposition, Civic Auditorium and Exposition Hall, Oakland, Calif.

Mar. 21, AIME, Western Section, Open Hearth Committee, Iron and Steel Div., Los Angeles.

Mar. 21-22, Combustion of Industrial Fuels, conference, sponsorship of College of Engineering, University of Michigan, Ann Arbor.

Apr. 2, AIME, Mexico Section, American Club, Mexico City.

Apr. 2-4, AIME, Open Hearth and Blast Furnace, Coke Oven and Raw Materials Conference, Iron and Steel Div., Statler Hotel, Cleveland.

Apr. 2-5, ASME, spring meeting, Atlanta-Biltmore, Atlanta.

Apr. 3, Society for Applied Spectroscopy, 6 pm dinner, Tosca's; 8 pm meeting, Socony-Vacuum Training Center, New York.

Apr. 3-6, Safety Convention and Exposition, Statler and Governor Clinton Hotels, New York.

Apr. 4-6, Midwest Power Conference, Sherman Hotel, Chicago.

Apr. 11, AIME, Chicago Section, Chicago Bar Assn., 29 S. LaSalle St., Chicago.

Apr. 13-14, AIME, Institute of Metals Div., New England regional conference, Taft Hotel, New Haven, Conn.

Apr. 15-18, Scientific Apparatus Makers Assn., annual meeting, Greenbrier, White Sulphur Springs, W. Va.

Apr. 16-18, American Society of Lubrication Engineers, Bellevue-Stratford Hotel, Philadelphia.

Apr. 23-26, American Foundrymen's Society, annual convention, Buffalo, N. Y.

Apr. 25-26, Metal Powder Assn., annual meeting, Hotel Cleveland, Cleveland.

Apr. 30-May 1, Assn. of Iron & Steel Engineers, spring conference, Hotel Statler, Detroit.

Apr. 30-May 4, Materials Handling Exposition, International Amphitheatre, Chicago.

Apr. 30-May 11, British Industries Fair, annual industrial show, Birmingham and London.

May 7, AIME, Florida Section, Lakeland, Fla.

May 7, AIME, Pittsburgh Section, Institute of Metals, Mellon Institute Auditorium, Pittsburgh.

May 7, AIME, Mexico Section, American Club, Mexico City.

May 9-11, Engineering Institute of Canada, annual meeting, Mount Royal Hotel, Montreal, Canada.

May 23-24, American Society for Quality Control, annual convention, Hotel Cleveland, Cleveland.

June 11-15, ASME, semi-annual meeting, Royal York, Toronto, Canada.

June 18-22, ASTM, annual meeting, Atlantic City, N. J.

Sept. 16-19, American Institute of Chemical Engineers, regional meeting—Sheraton Hotel, Rochester, N. Y.

Sept. 25-28, ASME, fall meeting, Minneapolis.

Oct. 1-4, Assn. of Iron & Steel Engineers, annual convention, Hotel Sherman, Chicago.

Oct. 3-5, AIME, petroleum branch, fall meeting, Oklahoma City.

Oct. 11-12, AIME, Fuels Conference, Roanoke Hotel, Roanoke, Va.

Oct. 15-17, AIME, Institute of Metals Div., fall meeting, Detroit-Leland Hotel, Detroit.

Oct. 15-19, National Metal Congress & Exposition, Detroit.

Oct. 22-24, Metal and Nonmetallic Mining Convention, Biltmore Hotel, Los Angeles.

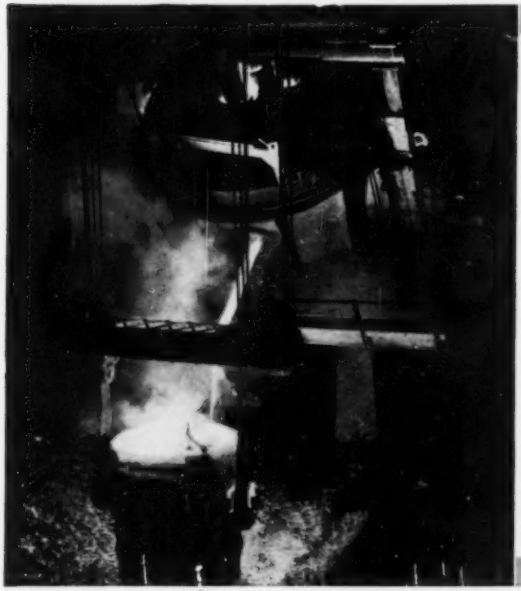
Oct. 25-26, AIME, Los Angeles Section, fall meeting, Los Angeles.

Oct. 29-Nov. 3, AIME, fall meeting, Mexico City.

Nov. 25-30, ASME, annual meeting, Atlantic City.

Dec. 2-5, American Institute of Chemical Engineers, annual meeting, Chalfonte-Haddon Hall, Atlantic City.

Dec. 6-8, AIME, Electric Furnace Conference, William Penn Hotel, Pittsburgh.



Heroult

ELECTRIC MELTING FURNACE

. . . as ever, the dependable furnace for the production of high-grade stainless, alloy and rimming steels.

Removable roof of new design now available for the larger furnaces.

AMERICAN BRIDGE COMPANY
General Offices: Frick Building, Pittsburgh, Pa.

Contracting Offices in New York, Philadelphia, Chicago, San Francisco and other principal cities
United States Steel Export Company, New York

USS **AMERICAN BRIDGE**
UNITED STATES STEEL

New Products

New Products | New Literature | New Services

For Further Information or Literature on any Product, Fill in the Coupon and Send to JOURNAL OF METALS

1—SAFETY GLASSES: New lenses, known as Soft-Lite HT-51, are available in safety glasses for people whose eyes are especially sensitive to light rays. The glasses, designed for dress as well as safety wear, were developed at the request of Soft-Lite Lens Co. by *Bausch & Lomb Optical Co.*

2—MAGNESIUM ANODES: For combatting corrosion, *Apex Smelting Co.* offers Anode-Pak units consisting of 17 or 32 lb magnesium anodes, packed with a chemically balanced backfill in a permeable cloth sack with a 10 ft insulated copper wire attached. Also available are 17, 32, and 51 lb anodes in bare metal, with or without attached wires.

3—WEIGHT INDICATOR: A newly redesigned weight indicator, that is accurate to one division of the scale, and has a dial reading line circumference of 47 in., is available from *W. C. Dillon & Co., Inc.* The weight indicator is especially advantageous where long or bulky objects cannot be moved easily to a central weighing point. Full compensation for tare loads has been provided.

4—PERMEABILITY METER: Latest developments in permeability testing are embodied in the new No. 335 Permmeter. Construction meets requirements for standard A.F.S. stopwatch permeabilities, and also provides for automatic permeabilities, independent of operator attention. *Harry W. Dietert Co.*

5—SELECTOR SWITCH: A new rotary selector switch for use in instrument circuits has solid silver contacts, totally enclosed construction, and multiple-leaf, self-aligning brushes made of durable silver alloy. Current interrupting capacity, tested for 100,000 operations, is 1-amp at 110 v, 60 cycles on resistance load, and contacts carry continuous current of 5 amp. Adjustable detent permits variation of switching torque. Switch is a shorting type, designed for 2-hole panel mounting per JAN and RMA standards. Various switching combinations are supplied, from single-pole, 12 position, to 6-pole, 12 position. *Leeds & Northrup Co.*

6—TUBE AND PIPE FITTINGS: A line of tube and pipe fittings, to simplify installation and reduce pipe line costs, has been announced by *Horace T. Potts Co.* Three principal fittings, which will be sold under the trademark *Speedline*, are an insert flange, an aligning connector, and a tube and pipe union. The fittings are available in corrosion resistant alloys. Specially designed auxiliary fittings such as tees, crosses, elbows are also produced to complete the range of *Speedline* fittings.

7—UNIVERSAL JOINT: A ball-type universal joint designed for light duty applications is available in ½, ¾, 1, and 1¼ in. sizes with single or double, solid or bored hubs. The joint has steel forks bearing upon a bronze ball, with heat-treated, centerless ground pivot bearing pins. *Curtis Universal Joint Co., Inc.*

8—SEALED-HUB WHEEL: A sealed-hub industrial wheel that excludes virtually all foreign matter responsible for excessive bearing and axle wear and deterioration, especially suitable for foundries, metal and woodworking shops etc., is now available at a cost only slightly higher than present prices on ordinary facilities. The Airlite Seal wheel is made from 6 to 20 in. diam by *Aerol Co., Inc.*, and has a convenient Zerk fitting which permits periodic lubrication of bearings and axle without tie-up of handling equipment.

9—SERRATING TOOL: An improved hand serrating tool for use with *Karbate* Brand Impervious Graphite pipe has been announced by *National Carbon Div., Union Carbide and Carbon Corp.* The tool is rugged in design, extremely easy to use, and provides an advantage over other types of piping since it facilitates quick assembly of *Karbate* pipe on the job site. Pipe sizes from 1 to 6 in. may be serrated.

10—HOT-COLD TEST STAND: Designed for testing small aircraft parts, the Hot-Cold Test Stand has a deep well for parts measuring up to 6x6x8 in., that can be maintained at temperatures from −70° to 230°F, for simulated service testing. Totally enclosed motors, automatic relief valves, and explosion-proof electrical components are incorporated into the test stand. *Electrical Mechanical Devices, Div. of George L. Nankervis Co.*

11—EMULSION CLEANERS: A cleaning process for all metals utilizing emulsion cleaners of the W/O type, based on petroleum products to replace hot chlorinated solvent degreasing, has been developed by *Northwest Chemical Co.* The process is adaptable to the smallest shop or the largest plant, with automatic or manual handling. Parts may be kept right on plating racks throughout the operation.

12—POWER PACKS: The Industrol Power Pack, specially designed for low voltage, regulated ac lighting and power service in factories and laboratories, incorporates in one steel housing an air circuit breaker, a dry-type transformer, and an air-cooled induction regulator. The new pack is available in single- or three-phase ratings, has a capacity of 15 to 100 kva, with an incoming circuit rated at 480 or 600 v, 60 cycles, and a regulated output at 120 or 240 v or 208Y/120 v. *General Electric Co.*

13—CORROSION-RESISTANT TUBING: *Carpenter Steel Co.* announces new tubular products, Carpenter alloys B and C, made from strip of the *Hastelloy* analyses, products of Haynes Stellite Div. of Union Carbide and Carbon Corp. Alloy B tubing or pipe is unusually resistant to hydrochloric acid in all con-

Journal of Metals
29 West 39th St.
New York 18, N. Y.

March

Please send me
- More Information ☐
- Free Literature ☐
- Price Data ☐

on items indicated

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40

Name ..... Title .....
Company .....
Street .....
City and Zone ..... State .....

centrations and at all temperatures, and is recommended for sulphuric acid at temperatures above 80°C. Alloy C will withstand strong oxidizing conditions such as those encountered with nitric acid, free chlorine, aqueous solutions of chlorine, acid solutions of ferric and cupric salts, phosphoric acid, acetic, formic, and sulphuric acids. Round tubing of these alloys is available, in sizes from $\frac{5}{8}$ to $4\frac{1}{2}$ in.; round pipe, schedules 5 and 10 in sizes $\frac{3}{8}$ to 4 in. I.P.S.; and schedule 40 pipe in sizes $\frac{3}{8}$ to 1 in. I.P.S.

14—EMERGENCY LIGHT: A portable lamp that provides 80 hr of continuous light on each battery charge has been designed for use in defense plants and in emergencies by police, fire, first-aid, rescue, and demolition squads. The light has a shatterproof lens, and employs a 2-filament bulb operated by a 3-way toggle switch. *Carpenter Manufacturing Co.*

15—BRIGHT HEAT TREATING: A unit consisting of a furnace sealed to a combination cooling chamber and quenching tank, is designed for bright heat treating, carburizing, carbonitriding, annealing, and copper brazing. The semi-automatic controlled atmosphere unit is rated at 100 lb per hr, has a 12x18x10 in. hearth, and a maximum operating temperature of 2100°F. Transfer of the work from this *Ipsen Industries, Inc.* furnace to the cooling or quenching section is done without breaking the atmosphere seal.

16—HOT-TOPPING COMPOUND: Mexatop, a hot-topping compound developed by *United States Graphite Co.* in conjunction with Lukens Steel Co., cuts the poured height of hot-tops by 2 in. and reduces metal in the hot-top by 1.5 pct. A desirable U-shaped cavity is obtained in the hot-top rather than the objectionable V-shape. Mexatop can be applied for 3c per ingot ton, and is said to be equally effective on casting risers.

17—CORROSION PROTECTION: Tinallium Pro-Tex-It, in the form of a non-drying black paste, constitutes protection against alkali, rust, corrosion, oxidation, heat, cold, steam, gas or sulphur fumes, brine, etc., either above or below ground. It is adaptable for all metals, woods, and concrete mixes, and will withstand contraction and expansion, is fire resistant and water repellent. *American Sand-Banum Co.*

Free Literature

20—AUTOMATIC MOLDING: The first publication of its kind describing the origins and growth of automatic molding, from the hand mold press to the fully automatic press, has been made available by *F. J. Stokes Machine Co.* The 24-p. brochure on Fully Automatic Molding of Thermosetting Plastics describes typical applications and cost savings.

21—TUBING AND PIPE: *Babcock & Wilcox Tube Co.* offers a stock list of alloy and stainless steel tubing and pipe.

22—FURNACES: A bulletin describing the complete line of standard rated atmosphere furnaces has been released by *Surface Combustion Corp.* The applications of these furnaces to modern, controlled atmosphere heat treating are described, as well as atmosphere generators, burner equipment, and compositions of widely used prepared atmospheres.

23—METAL PUNCHING: A multiple hole punching system for punching holes in sheet metal parts, permits setting up the entire job outside the stamping press or brake. The punch and die units are interchangeable, permitting re-use of the same units. Brochure M describes the system and equipment. *Wales-Strippit Corp.*

24—INSTRUMENTS: Acceleration of research through the use of industrial and related instruments and apparatus is described in a publication of *Brown Instruments Div., Minneapolis-Honeywell Regulator Co.* Extensive mention of devices of other organizations used in combination with its own instruments is made.

25—PRECISION CASTING: Case histories of precision cast parts of stainless steel, Stellite, and other metal parts are contained in a brochure of the *Microcast Div.*, of *Austenal Laboratories, Inc.* Illustrations of applications of this technique for a variety of precision parts are shown. Also, a 16-p. manual is offered, showing specifications and detailed explanations of each job.

26—CONTINUOUS CAST BRONZES: A 12-p. book on continuous-cast copper alloys in rod, tube, and shape forms is offered by *American Smelting & Refining Co.* Technical data, properties, and descriptions of the alloys are contained.

27—TUBE BENDING: A slide chart on minimum radii for economical bending of stainless tubing and pipe is offered by the *Alloy Tube Div., Carpenter Steel Co.* Sizes ranging from $\frac{3}{8}$ to 5-in. OD in BW Gages from 22 through 11 are covered by the chart. Coil diameters, standard sizes, bursting pressures, and properties of stainless tubing and pipe are included.

28—STRIP RECORDERS: An electronically operated strip chart recorder for measurement, indication, control, and permanent record of such variables as temperatures, speed, static strain loads, ac-dc voltage and amperage in process industries is described by *Wheelco Instruments Co.*, in its Bulletin C2-2. A price list supplements the bulletin.

29—8600-8700 STEELS: Nickel-chromium-molybdenum steels in the 8600-8700 series are described in a bulletin by *International Nickel Co.* Chemical compositions, critical ranges, anneal treatments, core tensile and impact properties, low temperature properties, annealed properties, tempered properties, and isothermal transformation diagrams are included.

30—TUNGSTEN CARBIDES: Hot pressed tungsten carbide physical properties, applications, shapes, and grades are described in bulletin SP-101, "Sinterforge Carbides," published by *Sintercast Corp. of America.*

31—CORRUGATED METAL PIPE: A new 16-p. booklet lists the types of full-round pipe and pipe-arch available from *Armco Drainage & Metals Products, Inc.*, to meet requirements for various types of sewers, culverts, conduits, and irrigation systems. Plain galvanized, asphalt coated, asbestos-bonded, and paved-invert pipe installations are described.

32—HOMOCARB FURNACE: Full control not only over temperature and time but also furnace atmosphere in such uses as hardening, annealing, normalizing, carbon restoration, and carburizing is claimed feasible with a new *Leeds & Northrup Co.* H Homocarb Furnace described in catalog T-623, Sec. 1. Microcarb Control permits automatic control of carbon content of the surface of steel to any selected point in the range of 0.15 to 1.15 pct C.

33—PRECISION CASTING: An 80-p. brochure contains engineering data on precision castings produced by the Mercast process. Step by step production is shown pictorially, and engineering, metallurgy, and inspection aspects covered. *Alloy Precision Castings Co.*

Another Good Technician for Your Laboratory!

"ALLOY 10"

HIGH TEMPERATURE

HEVI DUTY

MUFFLE FURNACES

The Hevi Duty "Alloy 10" Muffle Furnace is used efficiently in all laboratory operations where temperatures to 2350° F. are required.

If your type of operation includes the drying of precipitates, ash determinations, fusions, ignitions, heating metals and alloys, enameling and enamel smelting, ceramic firing or exact experimental test work, be sure to investigate these Hevi Duty High Temperature Muffle Furnaces. Write for Bulletin LAB-339 or —

SEE YOUR LABORATORY SUPPLY DEALER

HEVI DUTY ELECTRIC COMPANY

HEAT TREATING FURNACES HEVI-DUTY ELECTRIC EXCLUSIVELY

DRY TYPE TRANSFORMERS — CONSTANT CURRENT REGULATORS

MILWAUKEE 1, WISCONSIN

Short Cuts . . .

Ipsen Industries, Inc. moved its office and plant to 715 South Main St., Rockford, Ill.

Waterbury Farrel Foundry and Machine Co., Waterbury, Conn., celebrates its 100th anniversary. Waterbury Farrel's products today include: Cold process bolt, nut, screw, and rivet machinery; power presses and other metal products fabricating machines; wire, rod, and tube machinery; and rolling mill machinery and accessory equipment.

Newcomen Society and The Franklin Institute have awarded the Newcomen Medal for "achievement in the field of steam" to Isaac Harter, Chairman of the Board, Babcock & Wilcox Tube Co., Beaver Falls, Pa. Among Mr. Harter's achievements in steam were the furthering of research to remove diffused oxygen from boiler feed water and the application of this research to boilers into which were constructed economizers built with steel tubes.

Acme Steel Co. has been licensed by U.S. Steel Co. to manufacture *Cor-Ten*, corrosion resistant, high strength, low alloy steel developed by Carnegie-Illinois Steel Corp. Lukens Steel Co., Republic Steel Corp., Crucible Steel Co. of America, Inland Steel Co., Sharon Steel Co., Greer Steel Co., Colvilles, Ltd. (Glasgow, Scotland), and United Steel Companies, Ltd. (Sheffield, England) have also been licensed.

Aluminum Ore Co., Aluminum Co. of America subsidiary, will operate a new alumina plant to be built near Bauxite, Ark. The new plant, designed to process low-grade bauxite ore, will increase by nearly 50 pct the amount of alumina now being produced by the company.

Birdsboro Steel Foundry and Machine Co., Birdsboro, Pa., will build a combination strip, bar, and rod mill for Carpenter Steel Co., Reading, Pa. The roughing unit will consist of one 2-high reversing and one 3-high mill; the strip mill will be of 2-high construction; the bar mill will consist of 2-high mills; and the rod mill will include several looping stands with repeaters and a continuous 4-stand mill for finishing down to ¾ in. rounds and small flats.

Whitehead Metal Products Co., Inc. has moved its Baltimore metal warehouse to enlarged and improved quarters at 4300 E. Monument St., Baltimore. The expansion was necessitated by the increased demand by Baltimore's industrial firms for corrosion resisting metals.

Wilson-Snyder Manufacturing Div. of Oil Well Supply Co. will expand its line of centrifugal pumps to include types formerly manufactured by National Transit Pump and Machine Co., which liquidated all of its prop-

erties early this year. Wilson-Snyder is acquiring the patterns, drawings, tools, testing equipment and inventory for the National Transit pumps.

Lone Star Steel Co. will build a completely integrated steel mill adjacent to the firm's blast furnace, coke ovens and related facilities in East Texas. Iron ore is mined within sight of the blast furnace, coal is produced in company mines only 200 miles from the plant site, and major consumption of production is expected to occur within a radius of 300 miles of the plant. It is estimated that the steel plant would be able to turn out 500,000 tons of steel ingots from which 350,000 tons of welded steel pipe may be furnished.

1951 National Metal Congress and Exposition will be held Oct. 15 to 19, 1951, in Detroit, with the exhibits scheduled for the Michigan State Fair Grounds. Sponsors are the AIME, ASM, AWS, and SNDT.

General Electric will build a $1 million plant at Auburn to house its Electronics Dept. which produces radio and television sets and transmitters, receiving and picture tubes, communication equipment including microwave and carrier current, and a broad range of electronic equipment.

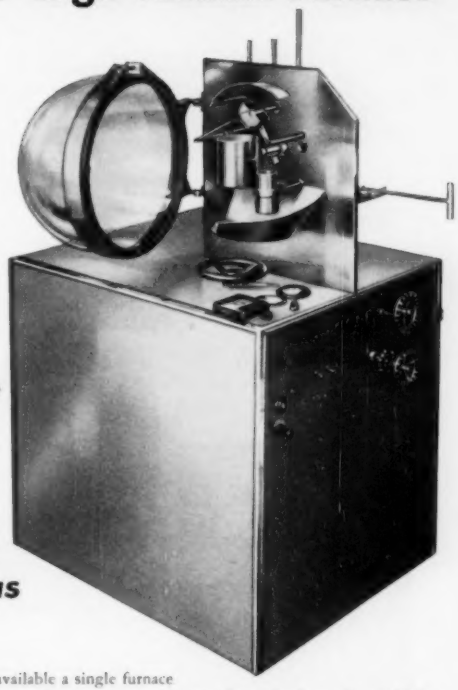
National Tube Co., a subsidiary of U.S. Steel, will install a large extrusion plant for the manufacture of high alloy seamless specialty tubes, as well as shapes and bars, at the Gary Works, Gary, Ind. Operation is expected to begin before the end of 1951, and production will be in the order of 3000 tons of special tubes and shapes per month.

Ingersoll Steel Div. of Borg-Warner Corp. will be separated into two independent units, Ingersoll Steel Div., New Castle, Ind., and Ingersoll Products Div., Chicago and Kalamazoo, Mich. The New Castle unit produces alloy steels, and solid and clad stainless steels. The Chicago plants make farm implement parts, truck wheel disks, washing machine tubs, steel sinks, bathtubs, and heat deflecting screens. Warm air furnaces, automobile stampings and forgings, agricultural implement parts, and storm windows are produced in Kalamazoo.

Ohio Works of Carnegie-Illinois Steel Corp. will increase blast furnace capacity by 112,000 tons a year with the rebuilding and enlarging of one of the plants furnaces. New turboblowers will replace obsolete, gas engine-driven blowers.

National Radiator Co. has purchased a steel fabricating plant at Danville, Pa. to handle expanded defense activities. The company is one of the largest producers of cast iron boilers, radiators, convectors, low pressure welded steel boilers, cast iron cooling and condensing sections, and iron powders.

NOW You can afford a High Vacuum Furnace



This **ONE** →

Versatile Unit lets you melt, pour, heat treat, degas

At last there is now available a single furnace that does away with the need to purchase equipment for each phase of your high-vacuum, high-temperature work. Because of its modest price, it will fall within the budget of most laboratories.

With this new furnace you can melt and solidify — melt and pour — add to the melt — stir — look into the hot zone — measure hot zone temperatures — introduce controlled atmospheres — degas — heat treat. It's a complete, versatile unit, capable of handling the widest variety of metallurgical research work. Write today.

FEATURES

- Ultimate vacuum of less than 5×10^{-5} mm. Hg.
- Working temperatures up to 2000° C.
- Temperature controllable within ± 5° C.
- Hot zone reaches temperature within one minute.
- No refractories used in hot zone.
- 4" purifying type diffusion pump insures high capacity for out-gassing.
- Utilizes single turn low voltage resistance element of either tungsten or molybdenum 8" x 2½" dia.
- Constant temperature zone 6" x 2½" dia.
- Power supplied directly from mains to specially-designed variable auto transformer which is an integral part of unit.
- Either manual or automatic temperature control or both.
- Thermocouple vacuum gage is standard equipment. Other gages are available.
- Furnished complete with vacuum system, controls and gages including ammeter, volt-meter and temperature indicator.

INDUSTRIAL RESEARCH - PROCESS DEVELOPMENT
HIGH VACUUM ENGINEERING AND EQUIPMENT

METALLURGY - DEHYDRATION - DISTILLATION
COATING - APPLIED PHYSICS

National Research Corporation

Seventy Memorial Drive, Cambridge, Massachusetts

In the United Kingdom: BRITISH AMERICAN RESEARCH, LTD., London S. W. 7 — Wishaw, Lanarkshire

— Personnel Service —

THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc., operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., **New York 18**; 100 Farnsworth Ave., **Detroit**; 57 Post St., **San Francisco**; 84 E. Randolph St., **Chicago 1**. Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service.

AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

POSITIONS OPEN

Welding Metallurgists, 25 to 50, B.S. degree in metallurgy or metallurgical engineering with 3 or more years' experience; or M.S. degree in metallurgy with 2 to 3 years' experience; or chemical engineer with metallurgical option; or mechanical engineer with metallurgical option. Experience in welding and research preferred. Will work with titanium, molybdenum, hardenable alloy steel, stainless steel, aluminum, copper, nickel and armor plate; and the development of welding processes for fabricating these metals. Work on process metallurgy, combustion, welding, physical metallurgy, physical chemistry. Must be U. S. citizen. Will have to be cleared for security purposes. Salary, $4800 to $6000 a year. Location, New Jersey. Y-4908(c).

Engineers. (a) Consulting Engineer with considerable background in metal working manufacturing. (b) Consulting Engineer for same work as above, except with electronic background. Salaries, $40 to $50 per day plus living allowance of $9 a day. Three months work. (c) Tool Designers with experience in designing tools and dies for small metal parts manufacturer. Location, Philadelphia. Y4893.

Metallurgist, graduate, with 6 to 8 years' experience in laboratory investigations covering beneficiation and reduction of nonferrous ores, including flotation, testing, roasting, smelting, hydro-metallurgy, gas measurement and analyses. Actual plant experience or pilot plant work desirable. Salary open. Location, Texas. Y4886.

Engineers. (a) Chief Engineer, graduate mechanical, experienced in large metallurgical or other process industry plant. Should have chemical engineering and/or metallurgical background, for the supervision of rehabilitation and operation of engineering and maintenance departments; steam and power plant and other utilities; design, purchasing and erection of new process equipment. Spanish desirable. Salary, $12,000 a year plus living quarters. (b) Plant Metallurgist, Master's degree in metallurgy or chemistry and experience in metallurgical, preferably hydrometallurgical, plant or in large chemical process plant. Duties will include production planning, process control, metallurgical accounting. Salary, $9000 to $10,000 a year. (c) Chief Chemist, Master's degree in chemistry, with some experience in analytical chemistry, preferably in inorganic chemical or metallurgical plant. Knowledge of modern analytical techniques, spectrography, etc. Duties will include supervision of control laboratory and plant sampling. Salary, $7200 a year. Location, Caribbean Area. Y4862.

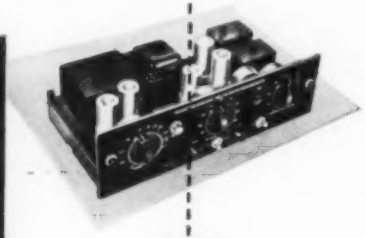
Sales Engineer, 30 to 40, with sales experience calling on metal manufacturing trades, in eastern area, to sell special processing equipment to stamping plants, foundries and general metal working concerns. Car furnished by company. Salary, $3600 to $7200 a year. Location, northern New Jersey. Y4834.

Research Fellowship in variety of fields including welding, induction heating, powder metallurgy, electrometallurgy and magnetic alloys. Post graduate work for M.S. or Ph.D. de-

YOU'LL GET ACCURACY

plus SIMPLICITY

Know Instrumentation is the Plus-Factor



WITH THE *Electr-O-Line*

ELECTRIC PROPORTIONAL CONTROL RELAY

Now YOU can attain the exact degree of accuracy dictated by your process. The *Electr-O-Line* with automatic reset makes it possible . . . delivers a steady modulated heat input . . . in a unit of simplified design and construction that adds new compactness and convenience to precise proportional control. It may be used as an integral part of any *ElectroniK* electric proportional controller, or as a separate element for modernizing existing installations.

A careful check of the list of its unique features will prompt you to call in your local Honeywell engineer for a discussion of how the *Electr-O-Line* can help improve your process. Branch offices in more than 80 principal cities of the United States, Canada and throughout the world.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4573 Wayne Ave., Philadelphia 44, Pa.

Check These Unique **FEATURES!**

- *Control adjustments are completely independent, making "tuning in" a process very simple.*
- *Manual control may be accomplished from the relay.*
- *Plug-in chassis simplifies wiring and servicing.*
- *Design is completely electronic, has no motor driven resistors.*
- *Can be used with a variety of instrument slidewire resistance values.*
- *Compactness and integral mounting permit the placing of two instruments with relays on one panel.*
- *Has widest range of control adjustments obtainable.*

Write for Catalog!

MINNEAPOLIS **Honeywell**

BROWN INSTRUMENTS

CARBON and SULFUR ANALYSIS with *Speed! Ease! Accuracy!*

TWO MINUTE CARBON DETERMINATOR

High degree of accuracy assured by: fan cooling gases, leveling to meniscus line, automatically maintaining atmospheric pressure, wide selection of carbon percentage scales. Accurate within 0.002% on low range burette.

THREE MINUTE SULFUR DETERMINATOR

Determination in accordance with A.S.T.M. specification accuracy within 0.002% inorganic or organic materials. Simple procedure.

HIGH-TEMPERATURE FURNACE

Sturdy construction with HIGHEST QUALITY insulation.

Use **3031D Boats and Zircotubes to reduce operating cost of analysis.**

Use Dietert-Detroit Carbon and Sulfur Determinators for Economical Analyses
Write to Dept. C-5 for descriptive literature

CONTROL EQUIPMENT
HARRY W. DIETERT COMPANY
9330 ROSELAWN • DETROIT 4, MICH.

gree. Salary, $1400 a year if single; $2100 a year if married, plus tuition fees. Position starts September 1951. Location, East. Y4828.

Metallurgist with aluminum powder production experience, to plan process improvements and supervise operations. Salary, $5000 to $6000 a year, plus bonus. Location, Long Island, N. Y. Y4827(b).

Metallurgist for academic research position in physical metallurgy and metallography. Must have some experience in laboratory on metal processing. Salary, $5200 a year and up depending on experience. Location, central New Jersey. Y4823.

Chemist, graduate, for analytical work on control type of analysis, for manufacturer of nonferrous metals. Should have some previous experience this type of work. Salary, $3960 to $4560 a year with extra compensation of $15 a month for occasional shift work. Location, Newark, N. J. Y4810.

Engineers. (a) Designer with considerable experience in the processing and layout of mining and smelter equipment. (b) Draftsman with mine and smelter experience, to lay out plant and machinery. Salaries open. Location, New York City. Y4808.

Foundry Consultant, 45 to 55, with at least 10 to 15 years' responsible charge of medium sized foundries. Salary, $50 a day plus $10 a day expenses. Location, Europe. Y4767.

Sales Engineer, 26 to 30, with metallurgical training and foundry experience, to do promotion and sales work on foundry accessories. Considerable traveling. Salary, $3600 a year plus bonus. Location, New York City. Y4586.

Metallurgical or Chemical Engineer, young, mining graduate, with considerable experience in ore flotation or dressing for the separation of various minerals. Location, Indiana. Y4521C.

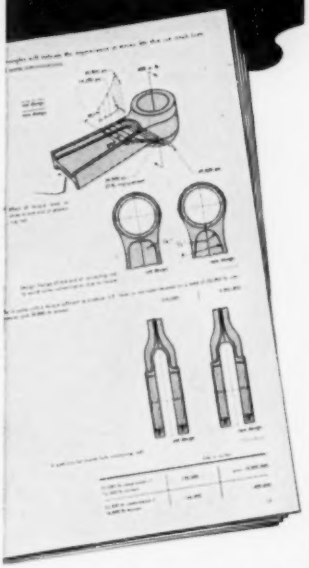
MEN AVAILABLE

Metallurgist, Met. Eng., 31; 3 years' metallurgical testing and control, nonferrous and rare metals, particularly for electrical usage. 1½ years' computing furnace charges for brass and phosphorous bronze. Knowledge electric furnaces. M-606-800-JM-Chicago.

High Temperature Metallurgist, 30, single, B.S. in Met. Eng. from Carnegie Institute. Experienced in alloy development, materials laboratory supervision and jet engine production and operational materials problems. Aggressive, responsible and capable organizer. Desires responsible position with progressive firm in supervision, development and/or technical control. M-613.

Evening Metallurgy Graduate, veteran, 26, married, (B. Ch.E. June 1951), now employed, desires position in development or sales, New York Metropolitan Area. M-611.

WHAT ABOUT STRESS RAISERS? *This book gives the answers..*



How to avoid the localized stresses which start failure is a basic problem of design. This 72 page booklet analyzes many good and bad features of design. It also deals with problems of steel selection and treatment from the viewpoint of the design engineer —instead of the metallurgist.

Write for "3 Keys to Satisfaction"—it is free.

Climax Molybdenum Company
500 Fifth Avenue · New York City

Please send your **FREE BOOKLET 3 KEYS TO SATISFACTION**

Name.....
Position.....
Company.....
Address.....

JM3 ©F21

Advertisement

ELECTROMET Data Sheet

A Digest of the Production, Properties, and Uses of Steels and Other Metals

Published by Electro Metallurgical Company, a Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. • In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario.

Extra-Low-Carbon STAINLESS STEEL

New Type Chromium-Nickel Steels Have Added Corrosion Resistance

New and improved austenitic stainless steels of the 18-8 type have been developed which have superior corrosion resistance after being exposed to heat. These steels, known as extra-low-carbon stainless steels, were designed especially for use in welded and stress-relieved equipment that is exposed to more severe corrosive conditions than are normally encountered by other types of straight 18-8 stainless steel.

Under severe corrosive conditions, intergranular attack may occur in some of the higher carbon grades of austenitic stainless steels that have been subjected to the temperature range of 800 to 1600 deg. F. during welding or hot forming operations. It is generally agreed that this type of corrosion is caused by complex carbides that are formed at the grain boundaries of the stainless steel during heating.

The effect of heat is rarely harmful in the ordinary fabrication of stainless steel for most applications, such as in architecture, the food and dairy industries, in hospitals, and in the home. However, in the chemical and other allied industries, where stainless steel is used in the handling of very corrosive chemicals, these new extra-low-carbon stainless steels should most certainly find wide use.

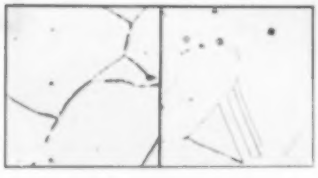


Fig. 1 Left: Carbide precipitation at the grain boundaries of an 18-8 stainless steel, containing 0.059 per cent carbon, after being held at 1200 deg. F. for 1 hour. Right: Absence of carbide precipitation in 18-8 stainless steel of 0.03 maximum carbon content, after being held at 1200 deg. F. for the same length of time.

In general, there are three ways in which the precipitation of carbides can be controlled in stainless steel:

1. Heat-treating so that the carbides present are dissolved.
2. Alloying with an element, such as columbium, tantalum, or titanium, that will tie up the carbon in the form of a harmless carbide.
3. Decreasing the carbon content of the steel.

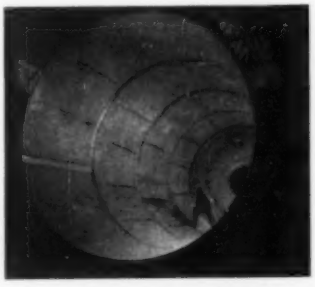


Fig. 2. The new extra-low-carbon stainless steels are especially suited for large types of process equipment, such as this fractionating tower. They require no heat-treatment after welding.

Heat-Treatment After Welding

Before the development of extra-low-carbon stainless steel, or of the "stabilized grades," one means for preventing intergranular corrosion was to heat-treat stainless steel that had been subjected to the dangerous temperature range, so that the precipitated chromium-carbides would go back into solid solution. It was found that when a welded part was heated to temperatures of 1950 to 2000 deg. F., and then cooled rapidly, most of the carbides were retained in solid solution. This extra heat-treatment is sometimes impractical, however, because of the design or massive size of some types of welded equipment.

Decreasing Carbon Content

A recent development in preventing intergranular corrosion has been the extra-low-carbon stainless steels. To be substantially harmless in stainless steel for as-welded or welded and stress relieved chemical equipment operating at temperatures under 700 deg. F., carbon must not be present in quantities over 0.03 per cent.

In 1937, ferrochrome with 0.03 per cent maximum carbon was first produced for the steel industry by ELECTROMET. This product has helped make it possible to produce very-low-carbon stainless steels—steels that are completely immune to intergranular corrosion after welding or after subjection to a stress-relieving heat-treatment.

The amount of stabilizing element that is necessary to "fix" carbon in stainless steel is in direct proportion to the carbon content of the steel. Therefore, the lower the carbon the less is the amount of stabilizing element required. Lowering the carbon content is an efficient means of conserving columbium, tantalum, and titanium.

Metallurgical Service Available

If you use welded stainless steel equipment, it will pay you to investigate the advantages of using extra-low-carbon steels. If you produce stainless steel, our metallurgists will be glad to give you technical assistance in the use of ferrochrome of 0.03 per cent maximum carbon. For further information, write to the nearest ELECTROMET office.

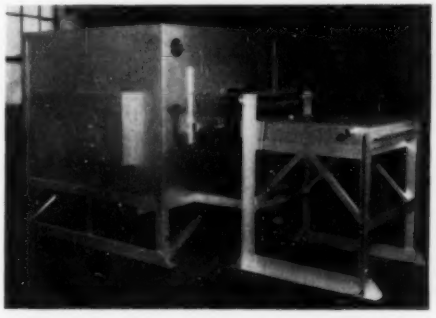
For a more detailed account of the properties of extra-low-carbon stainless steel, write for a free copy of the technical paper, "Resistance to Sensitization of Austenitic Chromium-Nickel Steels of 0.03% Max. Carbon Content".

The term "Electromet" is a registered trademark of Union Carbide and Carbon Corporation.

Senior Metallurgists. Positions available for appointment as senior metallurgists for service in Northern Rhodesia to supervise special research projects on base metal flotation and leaching problems. Applicants must be technically qualified and have minimum five years' responsible industrial experience. Salary and conditions of engagement to be negotiated according to qualifications. Box No. 576/5, Foster Turner & Everetts Ltd., 11, Old Jewry, London, E.C.2.

Assistant Manager. Position available for assistant manager to supervise metallurgical operations of a large copper enterprise including concentration, smelting, and refining. Applicant must be technically trained with good organizing ability, familiar with new developments, and with practical experience in all phases copper metallurgy. Preferred age 40 to 50. Location Northern Rhodesia. Salary to be negotiated according to qualifications and experience. Box No. 573/4, Foster Turner & Everetts Ltd., 11, Old Jewry, London, E.C.2., England.

HARPER WIRE ANNEALER . . .
ANNEALS 298,636 MILES OF WIRE IN 1 YEAR



The above 30-tube electric atmosphere furnace has been in continuous operation at a leading wire plant for the past two years without a trace of trouble.

Annealing of stainless steel wire in sizes of .020 to .0014" is done at the rate of 100 fpm at 2000°-2200° F.

Wire of exceptionally uniform quality is obtained as a result of closely maintained uniform temperatures possible in this furnace.

Harper Wire Annealing Furnaces are available in various sizes and what Harper has done for one mill can be duplicated for you. Write Dept. 10 for data.

HARPER ELECTRIC FURNACE CORPORATION
39 RIVER STREET, BUFFALO 2, NEW YORK
Representatives in Principal Cities

METALLIC SINGLE CRYSTALS

Single crystals of a variety of metals and alloys are now available in both standard rod form and special shapes. Orientation information, as well as crystals grown with specific orientation, can be supplied.

We will be glad to answer your request for information on prices, specifications, delivery schedules, and special problems in this field.

HORIZONS INCORPORATED

90 Nassau St. Princeton, N. J.
2891 E. 79th St. Cleveland 4, Ohio

RESEARCH CHEMIST or METALLURGIST

With experience in the development of processes for production of metals for work on new methods of producing titanium. Prefer man with M.S. or Ph.D.

National Research Corporation
70 Memorial Drive Cambridge 42, Mass.

Triple-alloy steels containing nickel offer designers the following *triple* advantages:

1. OUTSTANDING PERFORMANCE—Strength and toughness, resistance to wear, fatigue or shock to meet a wide range of requirements, as dictated by design.
2. RELIABILITY—based on consistently uniform response to heat treatment.
3. ECONOMY—resulting from standard compositions precisely graded to match the engineers' needs.

Service records established by triple-alloy steels over a period of years show that they are giving excellent results in many diverse and exacting applications.

The many standard combinations available permit accurate and economic selection for specific uses.

Because of their many advantages, these triple-alloy steels warrant your careful consideration when planning new or improved designs. We shall be glad to furnish counsel and data upon request.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 Wall Street New York 5, N.Y.

Capital cost of a nuclear powered electric generating plant of 50 mega-watts capacity is estimated to be about $15½ million compared to $7 million for a coal fired plant of the same capacity, according to British experts. Over 30 years operation, however, fuel costs with the nuclear generator would be between $2,800,000 and $11,200,000 as compared to $44 million for the coal plant.

The AEC has received proposals from two industrial groups who wish to bring their technical resources into the atomic energy program. One proposal was from Monsanto Chemical Co. and the other, Dow Chemical Co. and Detroit Edison Co. The proposals are to produce plutonium and other important materials together with power in a reactor and may ultimately lead to arrangements where, because initiative was with industry, additional incentives for rapid and technical development will exist.

Bethlehem Steel Co. is conducting a market survey of New England steel needs for business sponsors of the proposed steel plant to be erected near New London, Conn. While Bethlehem officials were noncommittal on the significance of the company's work on the project, it has been the aim of the sponsors of the mill to interest a private company in building and operating it. The mill is expected to have an annual ingot capacity of 1 million tons and be a completely integrated operation.

Sulphur resources in the U. S. are being rapidly exhausted with no new major deposits being found. This common mineral may be becoming one of the most strategic items during the next five years. Recovery of sulphur from pyrites is being considered in case of an emergency. Already the British have adopted stringent measures to conserve sulphur supplies.

A 10,000 gal storage tank can be set up in 10 min. This is a collapsible container designed by Army Reserve and Development Laboratories at Fort Belvoir and manufactured by Goodyear Tire & Rubber Co. The container is formed from a 3/32 in. thick sandwich of Buna N synthetic rubber and nylon cloth. A coating of liquid nylon 0.002 in. thick is applied to the inner surface under the Buna N to prevent leaks. The tank has been winter tested at -40°F.

A chlorine-caustic plant will be constructed for the Army near Muscle Shoals, Ala. to employ about 80 people. Monsanto Chemical Co. will design and build the plant.

The Dutch report a spectacular trial made with a new gold alloy. A 2400-lb automobile was hoisted a foot off the ground by a crane with the car suspended on an 85 grain gold wedding ring. An Utrecht firm had evolved this gold alloy with remarkable tensile and hardness properties.

Drift of Things . . . . . as followed by **Edward H. Robie**

WARTIME demands for metals have focussed attention of the Government on the mining industry to a greater extent than at any time in history. Bureaus in Washington are being established and expanded daily to insure mine production of metals, nonmetallic minerals, and coal in sufficient quantities to meet any national emergency. Ways and means are constantly being sought to throw Government money into mining enterprises and expansions. It is of this latter phase that some hardheaded consideration had better be given.

Subsidies and price parities, and occasionally actual Government operation appear to be the simplest and easiest ways to boost production. The long term effect of such practices on the mining industry, however, is questionable. Subsidies can and often do grow into Frankensteins (witness egg, butter, and potato subsidies) and not only open the door but eventually pave the way to Government ownership and Government operation. There certainly must be other ways of getting maximum production on what might be termed marginal or borderline properties. There certainly must be other ways of financing that will not only insure the operator that the development will pay for itself, but will insure the nation maximum production at a cost that is as economical as possible.

Such a method conceivably could be a loan-purchase arrangement. Under this type of plan, mine operators would do the development work, operate the mine and auxiliary processes, and eventually be permitted to acquire full ownership of a property. On the other hand, the Government would be assured of maximum production at a minimum cost.

By taking a hypothetical situation, the plan works out along general lines as follows:

Cobalt is in great demand. Under a normal world economy, the metal is imported almost entirely. However, the threat of war and its effect on shipping demands that some other sources, preferably domestic, be developed. There is cobalt ore in this country. It is low grade ore, a byproduct of mining of silver or other metals, and has not been given too much attention because the cost of production makes competition with foreign metal prohibitive.

The plan for development of domestic cobalt sources would be instituted by the Government. The Government would, after proper consideration and consultation with experienced mining men, finance the construction and development of a cobalt mining and processing property, including mining, milling, processing, and anything necessary to the production of desired cobalt metal or alloys. The company chosen to operate the mine or property would then arrange for its development and construction. Actually, the financing would be in the form of a loan to the company.

From the operation of the property, the company would pay back the loan by a prearranged but definitely established method. It could be on the basis that during the operation of the property, the company would keep 40 pct or 50 pct of the profit, and the remainder would be paid back to the Government to amortize the investment.

If, on the other hand, no profit could be made on the enterprise, the Government would maintain full ownership and pay the out-of-pocket expenses of the operation. When the critical need for the material is past, the Government would maintain the property in standby condition on a contract basis, as it did with many properties after World War II. This latter condition would occur only if cobalt could not be produced by this property at a profit. As long as the project is profitable, the company would continue to operate it and amortize the investment from profits. If uneconomical and placed in standby, at any time that it is deemed necessary to produce metal, the Government could reactivate the project, and the company would get back into production.

If the entire operation is mismanaged, the Government could call the company in for a review of the entire project. If it develops that the property is mismanaged, negotiations with other companies in the field can be started. If a new company does take over the project, it should do so where the old company left off and production would continue.

The whole idea behind the plan is: (1) Insure a sufficient quantity of critical materials during any national emergency; (2) Permit these materials to be produced by mining companies; (3) Give mining companies an opportunity to acquire properties that can be operated competitively under peacetime as well as wartime economies; (4) Keep Government out of industry and head off any trend toward Government ownership and operation of industry.

Obviously, a plan of such magnitude will have many facets and details that must be worked out. However, if these details are worked out with the purpose of the plan in mind, a healthier, stronger, more aggressive mining industry will result. Obviously, not all such projects will be able to withstand peacetime competition, and will have to curtail operations eventually. This is no great handicap. Instead, it is the same as a life insurance policy. The project is there, ready to operate when needed, yet a company is not saddled with a financial liability that would threaten its very existence in normal times.

While this plan might be adaptable to mining, there is no reason why it could not be applied to any of the basic industries, including steel. New England states have been juggling the idea of a new steel plant for some time, and at present it looks as though it will be completely Government financed.

While steel enterprises have not been subsidized by the Government, the loan-purchase idea may be appealing. It would eliminate any chance of real loss to the Government. Geneva Steel Co. was sold after the war at a figure lower than the cost of construction, and Kaiser Steel Co. still has involved financial arrangements. On the loan-purchase plan, the plant belongs to the Government until it is paid for, but as long as the operation is profitable its amortization is automatic.

If a change of pace and style of writing is noted in Drift of Things this month, it was because Mr. Robie, faced with a mountain of work for the coming annual meeting, was unable to write the column. Pinch-hitting for Mr. Robie was Thomas E. Lloyd, Editor, JOURNAL OF METALS.

Engineering Foundation Reports Progress on Fourteen Research Projects

Engineering Foundation, joint research organization of the four major engineering societies, summarized the progress on the 14 projects carried out under its sponsorship during the year ending Sept. 30, 1950. Three of these projects are in the field of mechanical engineering, five in civil engineering, four in mining and metallurgical engineering, and two are cooperative projects that cut across the whole engineering field. For the support of these projects the foundation made grants totaling $25,500, and industry and others contributed $967,045.

In the field of mechanical engineering, considerable progress has been made in increasing the accuracy of methods for measuring flowing fluids, in determining the forces needed in the rolling of metals, and in increasing the efficiency of large coal-fired boilers in power-generating plants by eliminating lazy surface, thus pointing the way to a more complete combustion of the fuel.

Much important work was done during the year in the field of mining and metallurgy. Noteworthy is the work at MIT on the self-diffusion of iron, in which radioactive iron, supplied by the Atomic Energy Commission, was used as a tracer. This work has shed new light on the structural changes that occur when steel is hardened by quenching; it has shown that these changes take place with split-second rapidity at a temperature only 4° above absolute zero. This refutes the previously advanced theory that such changes take place by atom-by-atom growth, in which case the changes would need centuries for completion at temperatures near absolute zero.

Oak Ridge Offers Courses in Nuclear Technology for Engineers

Industrial organizations interested in obtaining special training in nuclear reactor technology for engineers in their employ are invited to sponsor their enrollment in the 1951-52 session of the Oak Ridge School of Reactor Technology. Application deadline is April 1, and the school term begins Sept. 10, 1951. A limited number of recent college graduates are accepted in category A in the status of student employes. Category B students are selected from the applications sponsored by government agencies and private industrial firms interested in participating in the AEC national nuclear energy program. Such firms need not be connected with the AEC currently.

The majority of problems encountered in the field of nuclear engineering involve the same fundamental engineering and management skills common to industry generally. This school offers an opportunity for experienced engineers to obtain a thorough understanding of the specialized problems the AEC deals with in its nuclear engineering program. Further information and application forms may be obtained by writing to the Director, Oak Ridge School of Reactor Technology, P. O. Box P, Oak Ridge, Tenn.

Since much of the material presented in the curriculum of the Oak Ridge School of Reactor Technology will be classified, all enrollments are contingent upon a personal security investigation. Announcements of appointments will be in April.

Option Taken on Iron Ore Property

Pickands Mather & Co., acting for a group of steel and iron ore producers, is negotiating with Steep Rock Iron Mines, Ltd. an agreement to explore and an option to lease certain iron ore property in the Steep Rock Lake area in Western Ontario. Other members of the group are Bethlehem Steel Co., Youngstown Sheet and Tube Co., The Steel Company of Canada, Ltd., and Interlake Iron Corp.

While details of the agreement are still to be worked out, plans are going forward to begin a program of exploratory work. If sufficient ore should be proved, the company taking the lease will be managed by Pickands Mather & Co. The property being optioned covers more than 1,000 acres and is in the general vicinity of property which Inland Steel Co. optioned from Steep Rock Iron Mines a year ago and is now exploring. The area controlled by Steep Rock lies about 140 miles west of Port Arthur and Lake Superior, and is connected with Port Arthur by rail.

Navy Tests New Westinghouse 14,000 HP Thrust J40 Jet Engine

The most powerful turbojet engine in the world has successfully completed ground tests that qualify it for quantity production according to Navy and Westinghouse Electric Corp. spokesmen. The new jet, known as the J40, uses less fuel per pound of thrust than its predecessor, the J34, an engine that powers some of the nation's fastest planes.

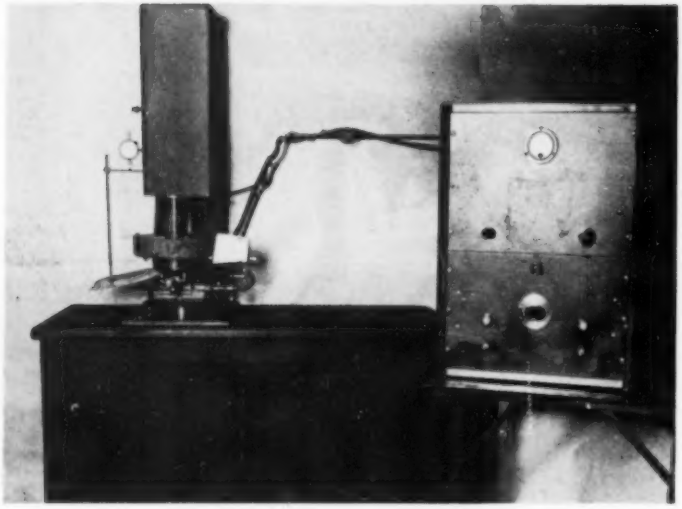
Designed by Westinghouse engineers under the guidance of the Navy Bureau of Aeronautics, the J40 packs more potential speed into less space than any previous rotating engine ever built. The thrust developed by the J40, equivalent to 14,000 hp at modern flight speeds, is for a bare engine, without thrust augmentation. The addition of an afterburner to reheat the exhaust gases, after they leave the turbine and before they emerge as a jet stream from the rear, together with other developments now in progress, is expected to almost double this figure.

Operation of the J40 in any high-performance military plane will actually be simpler for the pilot than driving his car. The engine's electronic control system is completely integrated and automatic, from standstill to top altitude and speed. From starting to full power, and under any condition of flight or altitude, operation of the engine is accomplished with a single cockpit control, equivalent to a throttle. All engine conditions are, in turn, automatically tied to this control.

Continuous Metalcast Corp. Formed

Continuous Metalcast Corp. was formed to take over the American and Canadian rights to the Junghans and Dunross continuous casting patents as well as other inventions, patents, engineering facilities and license agreements for continuous casting owned by Irving Rossi, president of the corporation. The new company controls all rights in the United States and Canada previously held by Mr. Rossi and will receive all future royalties and other benefits from those rights, regardless of when licenses were granted. Three metal companies also share in ownership of the new company: Allegheny Ludlum Steel Corp., which has been perfecting the process for continuously casting steel, owns 35 pct; Scovill Manufacturing Co., largest user of the process for the continuous casting of brass, owns 10 pct, and American Metal Co., Ltd., now using the process for copper, owns 10 pct. The remaining 45 pct is owned by Mr. Rossi. Continuous casting is a process whereby metal may be cast continuously into slabs or billets for rolling or billets for subsequent extrusion.

Directors of the new corporation include: Chairman of the Board, Hiland G. Batcheller; Directors, Irving Rossi, William M. Goss, Norman Hickman, Clark W. King, and Richard A. Hammer. Officers elected were: Irving Rossi, president; William M. Goss, vice president; Norman Hickman, vice president; Mark L. Sperry, II, secretary and treasurer; and Elizabeth Rufer, assistant secretary and treasurer.



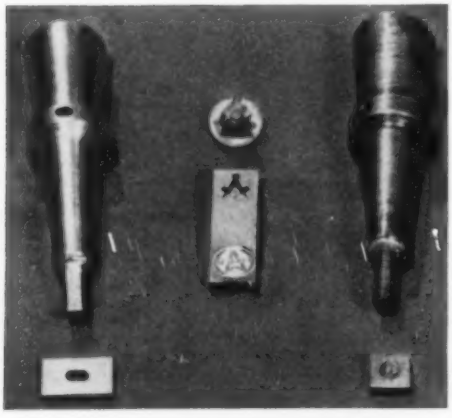
The Cavitron machine is compact, and does not require skilled personnel for operation.

New Method Machines . . .

Sintered Carbides
Sintered Borides
Hardened Tool Steels

by Alvin S. Cohan

Associate Editor, JOURNAL OF METALS



Carbide samples with odd shaped holes, emblems, and threads are shown with the tools used in their production.

CUTTING, threading, drilling, forming, and other machining operations on fully sintered cemented carbides and borides, stellites, hardened tool and die steels, and other hard and brittle materials such as glass, rubies, sapphires and diamonds are performed by a new machining method known as the Cavitron process. The Cavitron process uses ultrasonic vibrations and the machine is adapted for many totally new machining applications in the metals and ceramic industries.

Unlike conventional machining methods, Cavitron employs a blunt tool in the shape of the cut or hole to be made in the work. It operates *head on* into the work by vibrating 27,000 times per sec. High vibrating frequencies impart to the work tool accelerations in the order of 70,000 times the acceleration caused by the force of gravity. The actual cutting is done by a stream of inexpensive commercial abrasive, which is fed into the work area in a liquid carrier.

Holes, openings, and recesses having any arbitrary shape can be formed in the hardest materials in diameters from 0.007 to 2 in., with tolerances of 0.002 in.

The blunt tool is of any tough malleable metal, such as cold rolled steel, formed in the shape of the opening or impression to be made in the work. The tool is kept under slight tension against the work, which is held in a suitable jig. When the Cavitron machine is actuated the tool oscillates against the work while the liquid suspension of an abrasive such as boron carbide, is flowed over the work area. The extremely rapid tool vibrations hammer the abrasive particles against the work, causing myriads of chipping actions. The result is a smooth and rapid cutting into the hardest materials.

Previously, most machining operations performed on materials such as cemented carbides and cemented borides have been done on partially sintered pieces. In the case of die steels, machining is usually done before hardening. Methods have been employed to machine carbides, but processes involving burning away material in a high voltage arc often seriously affect the microstructure of the material. Also by heating up the work, stresses that defy relief are set up in the pieces. Diamond cutting and grinding is expensive.

The Cavitron process does not heat the work and in no way is the material affected chemically or metallurgically. Ceramics and other brittle materials can be machined easily with this method, because there is no shock effect of the tool on the work and the material is cut without being strained.

The most important feature of the Cavitron is its ability to perform operations on certain materials that have been difficult, if not impossible to machine. This includes putting internal and external threads on materials with a hardness R_c 85 to 94 and extends to the proposed use of putting the Christmas Tree patterns in the roots of hard metal, ceramal, or ceramic blades for turbines.

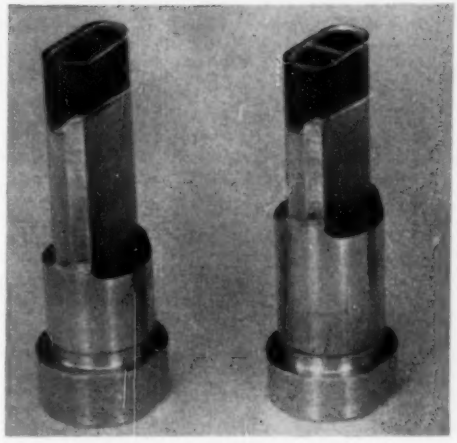
The method of cutting leaves an excellent surface finish on the work and no further finishing is necessary. For obtaining extremely close tolerances, it often is desirable to use a roughing tool, and follow this operation with a tool that will produce the desired size.

Maintenance of the machine is simple, because there are few parts exposed to wear. All rough action is taken up by the tool and abrasive, which are expendable. In addition, the machine does not require skilled personnel for operation, as it is virtually self-operating and foolproof once it is set into operation.

Among the applications on which the Cavitron has been successfully used include: Location of holes in hard materials, making of complex wire drawing dies, engraving letter dies, marking hardened tools and dies, cutting oil holes and key ways in hardened gears and gear cutters, producing form cutters, pill press punches and boxes, stamping dies, wear parts, and many others. Certain applications have been found for the machine that cannot be revealed, as they apply to work for the Defense effort.

The Cavitron Corp., New York, has licensed machines to Union Carbide and Carbon Corp., Kennametal, Inc., Hamilton Watch Co. and Coors Porcelain Co., according to Arthur Kuris, president of Cavitron.

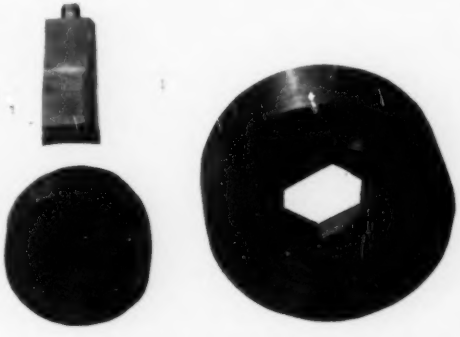
The Cavitron has extended and aided the field of metalworking, as well as opened up numerous possibilities for the powder metal and ceramic industries.



Above: Carbide pill press punches made by the Cavitron process are reported to outlast those made by conventional methods.

Right: Considerable savings were realized on ceramics prepared for printed circuits.

Below: Finished drawing dies are made directly from sintered carbide blanks.



Redesigning A

Secondary Smelting Plant

by Earl R. Marble, Jr.

IN 1932, the American Smelting and Refining Co. bought the Federated Metals Corp., and these properties became known as the Federated Metals Div. of the company. This division, now consisting of 12 plants, treats secondary nonferrous metals including copper, tin, lead, zinc, aluminum, and magnesium and their alloys. The Newark, N. J. plant, one of the original eight plants purchased in 1932, conducts secondary metals smelting and refining operations making tin and lead-base alloys from both scrap and primary metals, and produces zinc-base die casting alloys.

Part of the property was acquired by the State of New Jersey in 1948 for widening the southwest approach of the General Pulaski Skyway. The facilities totally or partially affected were the administration building, change house, chemical laboratory, shipping dept., fuel oil system, central heating system, and the warehouse. Interdepartment material handling was also affected. It was decided to expand certain plant operations at the same time facilities lost to the highway project were being replaced; and certain changes in the metallurgical flowsheet were to be incorporated into the design of the plant operating facilities. The plant was kept operating almost continually during the program, which started in 1947 and was completed in 1950.

The administration building and facilities building of brick and steel construction were completed in 1948. The new laboratory was completed in 1948. Each of the nine laboratory hoods is ventilated by a separate 1000-cfm fan exhausting through a lead stack. Refrigerated water baths are available for cooling titrations rapidly. A telautograph installation connects the laboratory with the smelting office and the manufacturing office, obviating the possibility of error in telephoning information by furnishing a written record.

EARL R. MARBLE, JR. is Assistant to Manager of Technical Operations, Central Metallurgical Dept., Federated Metals Div., American Smelting and Refining Co., Whiting, Ind.

The central research laboratory at Barber, N. J., has developed special analytical methods to meet particular requirements of the metallurgical practices in the Federated Metals Div. Especially useful at Newark are the colorimetric methods used for the accurate determination of impurities involved in the processes. Spectrographic analyses are made at the spectrographic laboratory for the division at Whiting, Ind., or at the central research laboratory.

Prior to rehabilitation, facilities for unloading and handling dross and metal were congested and poorly equipped. The new dross storage and handling building, 60x270 ft, provides three enclosed truck wells at one end with overhead bridge crane service. Rail receipts are unloaded from four locations along the track adjoining one side of this building. Drosses are unloaded by Hough payloader, fork lift trucks, 10-ton capacity overhead bridge crane, or hand trucks, and are weighed across two 10-ton platform scales, sampled, and placed in standard steel skip containers that hold 2500 lb of dross. More than 1000 of these corrugated steel containers are available, and they can be tiered six high by fork lift trucks or overhead bridge crane. Reclaiming of these units from storage is done by the same equipment. This standard container system of storage and handling is flexible and convenient, as individual lots of dross are kept separate and inventorying is simplified. The identity of the individual dross lots must be preserved until a settlement is reached with the shipper. Covered storage for the entire complement of these skips is provided by the new dross storage and handling building.

Raw materials and supplies are received at the plant by truck and rail. Truck receipts are weighed-in by a 50-ton truck scale installed in 1948. Rail receipts are weighed in over-track scales. Receipts consist of materials requiring smelting such as tin,

solder, and lead drosses; scrap metals such as tin, lead, solder, babbitt, type metal, and other tin or lead base alloys; primary tin, lead, antimony, zinc, aluminum, etc.; smelting and refining fluxes and reagents; fuel oil; and the usual operating and maintenance supplies.

Purchased drosses originate in industrial and commercial plants using molten tin, lead, solder, babbitt, or typemetal, and are bought from the company generating the dross or from dealers. These sources also provide purchased scrap metals and alloys. Primary metals are bought direct from the producing companies or from brokers. The operations at the Newark Plant, as at other Federated Metals Div. plants, provide an outlet for those primary metals produced by the parent American Smelting and Refining Co.

Most interdepartment material handling is by fork lift trucks. Six trucks are gasoline-electric Yale trucks of 6000-lb capacity, and one is a fluid-drive gasoline-powered Yale truck of 8000-lb capacity. Wherever feasible, palletizing is used in material handling. A warehouse building 60x230 ft provides storage for process metal, operating supplies, etc. To facilitate loading and unloading trucks and railroad cars, the floor level of all main plant buildings is elevated 3½ ft above track and roadway level.

Furnace Charge Preparation

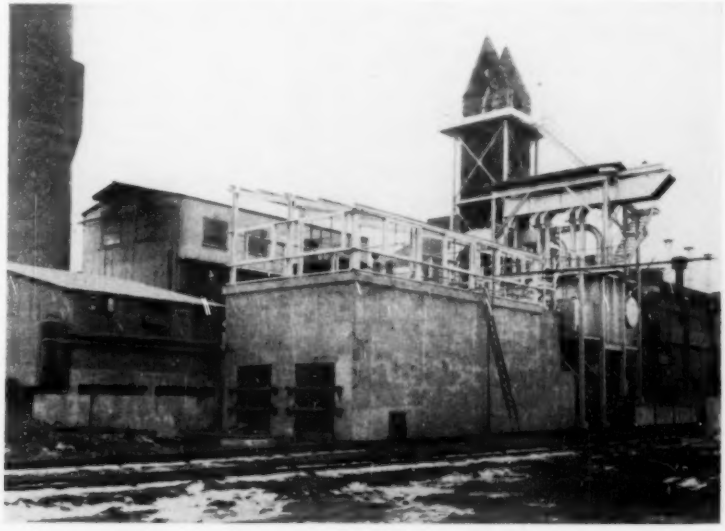
Furnace charges are mechanically mixed, as compared to hand-mixing employed prior to 1948. A 126 cu ft Ransome Mixer is used, mixing a 10-ton batch of charge in about 30 min. This mixer is located at the north end of the new dross storage building. Materials progress through this building from receiving, weighing, and sampling at the south end to storage in the central portion of the building, and eventual reclamation from storage for charge preparation at the north end of the building. Mechanical charge-mixing has increased the tonnage smelted per furnace day more than 10 pct with the same fuel consumption. Two 10-ton capacity platform scales near the mixer weigh charges. For the usual furnace operation, consisting of smelting a blend of tin, lead, and solder drosses to yield a tin-lead solder metal, fluxes used are lime, silica, and coal dust. The mixed charge is placed in steel skips and transported to the furnace by fork lift trucks.

Dross Smelting

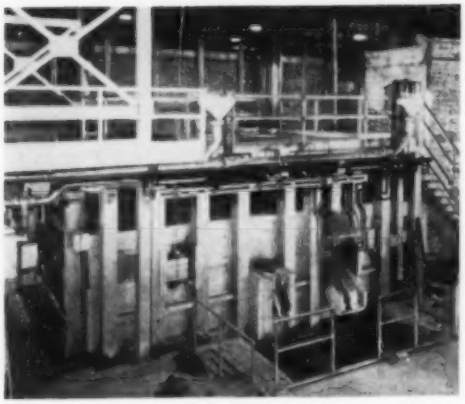
In 1946 dross smelting capacity consisted of six small shallow-bath reverberatory furnaces. These furnaces, replaced by three larger units, had been converted from coal firing on grates to oil. Each small furnace, with inside dimensions of 5x13 ft, smelted four 4-ton batches of charge per 24 hr, producing about 10 tons of metal per furnace day. A maximum of three furnaces were operated simultaneously. Some of these furnaces eventually were converted to top charging, but originally all had been hand charged through side doors. They were served by an overhead monorail system, which also was used for dross receiving and unloading purposes.

In 1947, the first new furnace was constructed. With inside dimensions of 7x20 ft, this furnace smelts five 7-ton batches of charge per 24 hr, producing about 20 tons of metal per furnace day. At the same time, a 10-ton overhead bridge crane was placed in service, replacing the furnace room monorail system. The entire smelted charge was tapped from the original furnace equipment into a stationary tapping kettle, from which the slag overflowed into a cascade slag pot arrangement. Metal was ladled from the tapping kettle by hand and cast into 50-lb pigs. On the new larger shallow-bath furnaces, the tapping ladle is designed with lifting lugs. The crane can pour the furnace metal into large pig molds holding 3000 lb of metal, or directly into refining kettles located under the furnace room craneway. Slag overflows from this tapping ladle into a cascade slag pot arrangement, and the slag pots are handled by the crane. The average grade of crude furnace metal produced by the smelting operation is 28 pct tin, 1.5 pct antimony, 1.5 pct copper, and the balance lead.

During 1948, development work with other dross smelting reverberatory furnaces demonstrated the



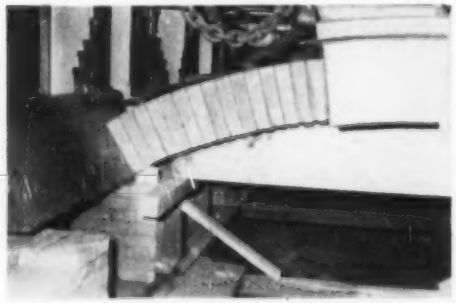
The tubular heat exchanger in the flue system cools furnace gases after passage through radiation coolers. This part of the flue system and the spray chamber that follows the tubular heat exchanger are shown here.



One of the two deep-bath reverberatory furnaces used in dross smelting. After considerable experiment in furnace design, this type was chosen because of low fuel cost, less fume generation, low repair costs, and longer furnace campaigns.

practicability of using the deep-bath type of furnace. Two deep-bath reverberatory furnaces were built in 1949 and 1950. These furnaces are 8x20 ft inside, and provide for a 36-in. bath depth. Advantages of this type furnace are: Decreased fuel consumption per ton smelted; less byproduct fume generated per ton smelted; lower repair costs per ton smelted; and longer furnace campaigns resulting in an increased operating factor.

The water-jacketed top-charge holes are located along the center line of each furnace. On these furnaces the two rabbling doors and the two charge-hole doors are pneumatically operated. The doors are controlled by valves located at the working floor level. Furnace charges are dropped directly by the furnace room crane, but provision has been made in the design for eventual mechanical charging. The charge then would be stored in elevated hoppers at the burner end of the furnaces, and either vibratory feeders or drag conveyers would charge the furnaces automatically. These two furnaces are each fired by two 6-in. Hauck proportioning oil burners, using air at 32-oz pressure supplied by Spencer turbo-blowers. Furnace draft is automatically regulated on each furnace by Askania controls. The automatic draft control regulates the position of a water-cooled damper located in the connecting flue between the furnace and the main flue. A Leeds and Northrup Micromax flow-recorder indicates and charts fuel oil consumption on each furnace. All furnace controls are centralized on a steel panel located inside a closed control room supplied with filtered air.



Arch construction in reverberatory furnace. The arch is sprung between a copper water-jacketed lintel and a charge-hole water jacket, over a rabbling door.

Copper side-wall water jackets are used on the furnaces around the entire bath line. Side walls at and below the bath line are basic brick, and the inverted arch bottom, side walls above the bath, and the 12-in. sprung arch are 70 pct alumina fire brick. Metal is tapped from the furnaces through a lead well, and matte and slag are tapped through either of two copper water-jacketed tapping slots. Metal, matte, and slag are tapped into 30 cu ft capacity cast steel ladles which are handled by the crane. Matte and slag are cast into buttons in cast steel pots of 15 cu ft capacity. Matte is shipped into a copper smelter and the slag is discarded if low in metal values. Slags containing metals of sufficient value are returned for resmelting. Matte results from the operation conducted on high copper-bearing drosses segregated out of the purchased receipts, together with high copper-bearing plant byproducts. Soda matting practice is employed in accordance with the process developed by E. P. Fleming and D. H. McIntosh of the American Smelting and Refining Co. Each furnace smelts 40 tons of charge per operating day, producing 25 tons of metal per furnace day. Fuel oil consumption is at the rate of 150 gal per hr per furnace. Ventilation hoods over rabbling doors and at the tapping pots collect fumes. This ventilation smoke is filtered in a small Northern Blower Co. baghouse.

Furnace Flue System and Gas Handling

Gases from the smelting furnaces are handled by a new flue system built in 1950. This arrangement consists of a main brick flue, 5 ft wide and 7 ft high, inside dimensions, into which all furnaces discharge. This main flue leads into a water-jacketed steel flue section 30 ft long, and first cooling of the gas is done in this section. Water-jacketing is necessary because of the high temperature of the gases and to provide a high rate of heat transfer. From the jacketed flue section, gas passes through a pair of large inverted U radiation coolers in parallel, and then enters a tube heat exchanger. In this cooler the smoke passes around closely spaced tubes through which cooling air of controlled volume is circulated. The fan circulating a controlled volume of air through the cooling tubes is driven by a variable speed motor, regulated by a pyrometer measuring the temperature of the exit gas passing on into the spray chamber. These automatic controls maintain the exit gas from the tube cooler at 700°F. The concrete spray chamber that follows the tube cooler, and provides further cooling, is lined with acid resistant Duro brick, and is equipped with 30 water sprays operating at 500 psi. The temperature of the gas leaving the spray chamber is automatically regulated by a pyrometric control coupled to the valves controlling the banks of sprays. An acid atomizer at the entrance to the spray chamber introduces sulphuric acid into the smoke when necessary for proper Cottrell operation. Conditioned gases, leaving the spray chamber at 400°F, enter the main fan supplying draft for the system, and then pass into a Cottrell treater of the wire and plate type for dust collection. The main fan is driven by a variable speed motor coupled to Hagan draft controls, which serve to automatically

maintain the desired negative pressure at the inlet to the tube gas cooler.

Dust Recovery and Treatment

The Cottrell precipitator, built in 1941, was expanded 100 pct in 1948. Four 15 kva mechanical rectifier units supply 44,000 v, dc, to the Cottrell treater. When operating two smelting furnaces, about 10 tons of dust per day are recovered. This Cottrell dust analyzes 22 pct tin, 32 pct lead, and 14 pct zinc. Recovery is over 98 pct of the burden of solids imposed on the treater. From the Cottrell, the gas passes into a 150-ft brick stack. Stack gases are automatically sampled on a continuous basis to determine stack losses and Cottrell efficiency. This type of smoke sampler has been described in an AIME paper by J. J. Donoso of the American Smelting and Refining Co.[1] The Cottrell treater, draft fan, and all flues following the spray chamber are insulated.

Cottrell dust is transported to a leaching plant for removing zinc and chlorine prior to resmelting. These impurities, present in many of the drosses smelted, become concentrated in the Cottrell dust. Leaching provides a means for their removal. A sulphuric acid leach is used, and the dust is treated in batches of seven tons. Steam is used to heat the leaching tanks, holding 6000 gal of solution at 170°F to accelerate the operation. Two-step leaching is used. New acid is reactivated with partially leached dust to complete the second step of the leaching process, and this partially spent acid is decanted off the second step tanks to be used in partially leaching the new dust as the first step. The leached slurry is filtered through plate and frame filter presses. Final filter cake analyzes 2 pct zinc and contains 30 pct moisture. This cake is dried to 10 pct moisture in a rotary drier to eliminate hazards when charged into the furnaces for resmelting.

Refining Furnace Metals

Two 25-ton refining kettles were installed in 1947, during the construction of the first new smelting furnace, for use in the development of kettle refining methods to replace the old sweater liquation process previously used on crude furnace metal. The procedures developed with these kettles increased the direct yield of refined metal, and the kettle-refined metal can be made of a higher purity than that obtained by alloying commercial primary metals. This has resulted in a decreased run-around of plant byproducts because of the higher concentration in these byproducts of the impurities being removed.

Crude furnace metal is now refined in four 50-ton kettles installed during 1950. The first step is a dry drossing operation to remove inclusions of slag, matte, etc., followed by de-copperizing using sulphur. These oil-fired refining kettles are equipped with automatic temperature regulation using Leeds and Northrup Micromax controls. Refining methods have been developed for the removal of copper, nickel, iron, arsenic, antimony, zinc, aluminum, magnesium, sulphur, lead from tin alloys, and tin from lead alloys. These kettles are well hooded, with each pair of kettles ventilated by a 25,000 cfm fan. This operation is serviced by the furnace room crane.

Refined metal from these kettles is cast as 3000-lb pigs, or on a casting machine making 90-lb pigs. The pig casting machine can cast a 50-ton lot of metal in 1½ hr. The 3000-lb pigs used for handling process

A new flue system was built to handle gases from the smelting furnaces. Shown here is the end of the main reverberatory brick flue where furnace gases enter the water-jacketed flue section.

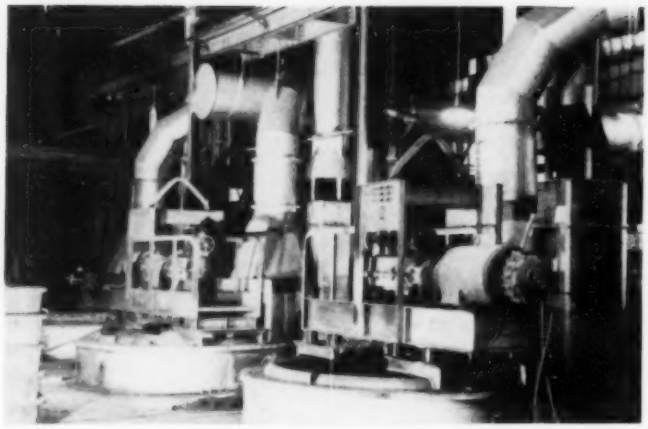
metal at the Newark Plant are similar to the 10-ton lead blocks described by K. Harms and T. D. Jones in an AIME paper.[3] These 3000-lb pigs have a large tapered steel screw cast into the top, and are handled with Heppenstall tongs by fork lift trucks. The pigs can be tiered in stacks enabling efficient utilization of available storage space. Some metal from the refining kettles is made as a directly saleable finished product, and the balance is used in succeeding plant processes.

Processing Refined Metal

Metal from these kettles, if not made to a specification for direct sale, is used in the manufacturing depts. The kettle dept. refines and alloys metal to specification in seven oil-fired kettles of from 5 to 25-ton capacity, then casts large solder, babbitt, or typemetal shapes.

The casting dept. hand casts small solder, babbitt, and typemetal shapes from 16 oil-fired kettles of 2-ton capacity each, or mechanically casts shapes in closed molds on a Castomatic machine, the latter being a form of permanent mold casting developed by S. L. Palmer and L. M. Beckes of the Federated Metals Div.[2] Casting dept. kettles were converted from coal to oil-firing in 1949, and automatic temperature regulation using Partlow controls was installed in 1950.

The wire dept. extrudes flux core and solid wire solders in hydraulic presses of from 600 to 1350-ton capacity. In this process extrusion billets, weighing about 100 lb each, are cast in water-cooled molds, extruded by vertical extrusion presses, and the resulting wire spooled direct if extruded to size or reduced to proper gage on drawing machines and then spooled. Extrusion presses are equipped with



Crude furnace metal is refined in four 50-ton kettles, two of which are shown here. Temperature regulation is automatic. Metal is then cast into pigs.

operation recorders providing a chart of the press cycles.

The die cast dept. produces zinc-base die casting alloys in four kettles of 5000-lb capacity each.

From the manufacturing depts., metal products are transported to the shipping dept. for packaging, weighing, and shipment by truck or rail. A balcony over a portion of the shipping floor provides area for box making and storage, and is served by an Otis hydraulic elevator of 2500-lb capacity. The 50-ton truck scale checks shipping weights on trucks, and rail weight checks are made by track scales. More than 2000 tons of metal products are shipped from the plant each month, including hundreds of different chemical compositions and physical shapes made available in dozens of various packages.

Utilities and Services

Before the rehabilitation program, power for general plant use was 440 v, two-phase, 60 cycle, ac. As a part of the rehabilitation program the entire plant electrical system has been changed to 440 v, three-phase, 60 cycle, ac. Power is purchased from the Public Service Co. of New Jersey and enters the plant at 4160 v. Emergency service is provided by a separate tie-in connecting the plant to a different Public Service Co. substation. Three 500 kw unit substations transform the 4160 v to 440 v for plant use. These substations are centrally located with regard to their respective loads. Where the concentration and number of motors warrants, motor control centers are used in the new electrical layout.

Steam for plant heating and process purposes is generated in two Erie City *Economic* boilers. One boiler is rated at 300 hp and the other at 150 hp. Both boilers are oil-fired and completely automatic. Large volumes of cooling water are required for furnace water-jackets, water-cooled flue sections, and water-cooled molds, so a water recirculating system was installed in 1950. This system has minimized the requirements of city water. Hot process water is returned to a 100,000-gal concrete hot well from which four 1000-gpm pumps circulate the water over a two-section Marley induced-draft cooling tower. The concrete cold well is directly beneath the cooling tower, and holds 50,000 gal of water. From the cold well, four 1000-gpm pumps return the cooled water to plant operations. A 75,000-gal elevated steel storage tank of the Horton type, built by the Chicago Bridge and Iron Co., provides a reservoir of water on the pressure lines. The operation of this water system is entirely automatic.

Bunker C grade fuel oil, used by the smelting furnaces and boilers, is stored in a 300,000-gal storage tank. Oil is received in tank trucks and rail tank cars. Light fuel oil of No. 4 grade, used by the kettles and where operating temperatures do not permit efficient utilization of heavy oil, is stored in two 15,000-gal tanks. Both heavy and light oil are circulated through the plant in *loop* systems.

High pressure air at 90 psi is furnished by a 500-cfm Ingersoll-Rand compressor and a 150-cfm Ingersoll-Rand compressor.

Safety, Welfare, and Employment

Newark Plant safety and welfare are under the direction of a plant safety director. Employees are furnished proper safety equipment for their respective jobs including goggles, leggings, toe guards, etc. Adequate lighting has been provided for all plant areas as part of the rehabilitation program. In the furnace dept., dross storage building, wire dept., and shipping dept., a combination of mercury-vapor and incandescent lighting is used. In the administration building, laboratory and change house, flushmounted ceiling fluorescent lighting fixtures are installed.

Operations at the Newark Plant are carefully observed by the company's hygiene dept. Primary consideration was given to dust and fume control in designing all facilities installed. An example is the furnace room crane cab air-conditioning. In this installation, the cab itself is completely insulated, and the air is filtered through a small baghouse mounted on the cab, then cooled by a Dravo Corp. Type C-5 crane cab conditioning unit. Every man working in a plant area requiring the wearing of a respirator receives a sealed paper pag containing a clean sterilized respirator at the start of each shift.

References

[1] Journal of Metals (1950) **188**, p. 610.
[2] Mining and Metallurgy (1946) **27**, p. 391.
[3] U. S. Patent No. 2,459,892.

Continuous Casting of Steel

At Babcock & Wilcox Tube Co.

By Isaac Harter, Jr.

DEVELOPMENTS in continuous casting of steel are being made jointly by Republic Steel Corp., and Babcock & Wilcox Tube Co. Efforts are to simplify or eliminate some of the present steps in making steel products, and to reduce the capital and operating costs now required in making steel. Upon completion of this development, other companies will be licensed to use the process.

Growth and changes in the steel industry have brought about a need for decentralization, and continuous casting has advantages under these conditions. It will change or replace certain steps in steelmaking.

During the 1800's the rapid growth of population generated a vast market for both quantity and variety of steel products. To meet this demand, better methods and better machines were developed; the progressive companies grew large; others went out of business because they could not meet the lower operating costs of the better mechanized companies. The increase in the variety of products required led to separating the industry into two manufacturing groups. The first group, the integrated companies, begins with the basic materials—iron ore and coal—and carries right through to finished products. The second group, referred to as non-integrated companies, buys semi-finished steel for conversion into finished products. Important in the gradual disappearance of these non-integrated companies was the fact that larger companies that sold them raw materials—semi-finished steel—and whose prices for finished products they had to meet in the open market, so reduced their manufacturing costs and prices as to leave little companies less and less margin for profit. Invention and improvements in methods also made existence difficult for the non-integrated company. The most striking example of this is the introduction of the high speed sheet rolling mill, which in a few years ended the existence of the small sheet mills. The investment in these modern high speed mills has already exceeded $1 billion.

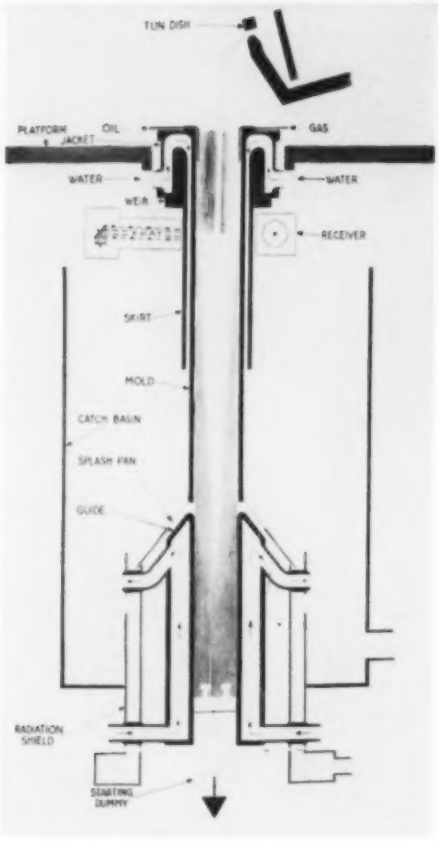
There are, at present, signs that this centripetal phase is reversing, and that the industry will spread into smaller plants, with an increase in the number of companies engaged in making steel. This change will result from: (1) The spreading out of other industries, which has been so marked in recent years. (2) The continual increase in cost of raw materials, finished products, and transportation. (3) The need to obtain more ore outside the U. S. (4) The need to reduce both the size of plant and the geographic concentration for reasons of military security, and to obtain improvements in management and social conditions. While these forces tending toward decentralization are strong, the rate of reversal is slow because of the capital now invested in existing plants.

Circumventing ingot casting, soaking pits, and the blooming mill, by going directly from the melt to a casting, equivalent in cross-sectional area to a bloom, would obviously be a considerable saving. It would benefit the big producer who wanted to build an isolated plant or replace obsolete equipment, and the small producer seeking ways to cut costs. These are the steps that continuous casting of steel eliminates.

In addition to eliminating a great amount of expensive equipment, continuous casting delivers to the finishing mill a high percentage of the metal originally melted, avoiding much of the scrap loss incurred in many conventional metal processing steps. In stationary casting, the top and bottom must be cropped from each ingot. This loss averages approximately 18 pct, and, since the entire heat is cast into ingots, this percentage remains constant regardless of the size of the heat. On the other hand, while a continuously cast heat must be cropped both at the top and bottom, two advantages are

ISAAC HARTER, JR., is Engineer in Charge of Continuous Casting, Babcock & Wilcox Tube Co., Beaver Falls, Pa.

This paper was presented at the Electric Furnace Steel Conference, Dec. 7, 1950, at Pittsburgh.



This schematic mold assembly shows the Babcock & Wilcox Tube Co.'s method of continuous casting. Metal flows from a furnace (not shown) through a tun-dish into the mold. The X-ray apparatus maintains metal level, and the mold is water-cooled.

evident. First, the cross-section is smaller and, therefore, the crop loss is less and second, as this pound loss remains constant, the percentage of total loss decreases with an increase in the size of heat. Incidentally, the value of the material saved increases with the cost of the product.

Approximately 100 years ago, Sir Henry Bessemer became interested in the possibilities of continuous casting of steel, and obtained a patent. Examples of his attempts are still in existence. In recent years, continuous casting of brass, copper, and aluminum has been developed and practiced on a commercial scale. The first commercial continuously cast steel ever made, amounting to a few tons which Babcock & Wilcox Co. produced during experiments, was not shipped until 1947. While about 600 tons of good quality steel have been made and tested, there is, as yet, no plant running anywhere in daily production.

Reasons why nonferrous metals have been cast commercially and why steel has not are easy to find. In the first place, molten nonferrous metals contain much less heat. Molten copper contains only about 60 pct, and aluminum only about 30 pct as much heat as steel. Second, the pouring temperatures of these metals are lower. For copper it is about 75 pct, and for aluminum about 45 pct that of steel. Third, the thermal conductivity of steel is less than that of the nonferrous metals. The conductivity of copper is ten times greater and aluminum three times greater than that of steel. In addition to these apparent obstacles, steel, because of its low unit price, must be cast about five times faster than copper and about 15 times faster than aluminum. A particularly important point that has held up the progress of the continuous casting of steel is that there are no materials that molten steel does not either erode or dissolve.

In continuous casting steel at Babcock & Wilcox, the furnace can either melt steel scrap or receive molten steel from another furnace. In either case, the furnace then maintains the correct temperature of the steel while casting and delivers the metal at a uniform rate. Since steel must be protected by a slag layer, some of this slag may be entrained by the stream of molten metal. A vessel known as a tundish has been interposed, to separate the slag from the steel, and to serve as an easily movable means of directing the stream of steel into the proper place in the mold.

The Babcock & Wilcox continuous casting mold is an open-ended brass tube, cooled by the use of high velocity water racing downward over its outer surface. During the cast, a small amount of inert gas, argon, and a minute quantity of a combustible oil, is continuously introduced into the upper end of the mold, to exclude and absorb oxygen. The casting is allowed to move from the lower end of the mold at a pre-selected speed, dependent upon the casting size. The rate is governed by spring loaded rolls operating as a running brake.

To start a cast, a leader or dummy bar is threaded upward through the rolls, and a close fitting head is installed on this bar to form a temporary bottom in the mold. The first metal cast, freezing around the protruding bolts in this head, locks the casting to the bar, which guides the casting downward through the after-coolers and rolls. A means of cutting the casting to the desired length is located below the rolls. The severed casting is then lowered to the ground and discharged as semi-finished steel. This product is then ready for reheating and rolling on a conventional finishing mill.

There are seven basic requirements for successful continuous casting of steel: (1) Steel composition control, (2) pouring temperature, (3) slag separation, (4) proper mold design, (5) automatic pouring control, (6) proper casting cross-section, and (7) auxiliary cooling below the mold. The problems in continuous casting are related like the links in a chain, so that each link must be present and united.

A heat of steel is ready for pouring when it has been brought to the required analysis and temperature. Whether cast into ingots or continuously cast, undue delay in casting is harmful because of the rapidity with which steel reacts with air and other gases. Improvement in this respect should be made in both casting processes, and improvement may well turn out to be simpler to make in the case of continuous casting. With care, the arc furnace makes it possible to hold composition for the duration of a cast.

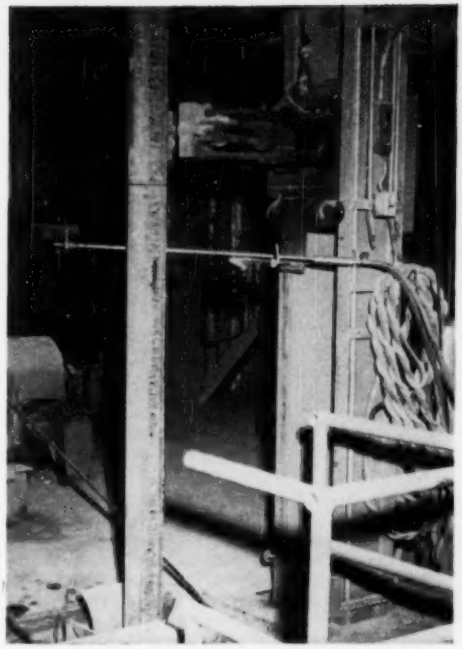
Experiments show that the entire cast should be made within a 50° temperature range. This re-

quires control of temperature by supplying heat to the molten steel during pouring, which is done by a heated holding and casting ladle, the heat being supplied either by electric induction or by an electric arc. The objection to the former is the necessary water cooling of the induction coils, which creates the risk of a serious accident if molten metal breaks through the ladle lining and reaches the water. The objection to the arc furnace, with its saucer-shaped bath, is its larger size for a given amount of metal.

In conventional pouring of steel, slag rises to the top of the ladle and the stream comes through a nozzle in the bottom. Slag and metal are related in weight about as wood chips are to water. Hence, bottom pouring is a good separator. Bottom pouring cannot be used in continuous casting because it does not provide a uniform flow. The flow through a bottom-pouring nozzle varies with the fullness of the ladle. No refractory is known yet that will not change in size when molten steel flows over or through it for a long time. Thus, a top-pouring ladle is used. In pouring from the furnace, some slag escapes with the steel, and this slag must be prevented from entering the mold by the tun-dish. This tun-dish has an inverted weir, which acts somewhat as the bottom-pouring nozzle does in the conventional process. The mold must be slag free. If slag wets or sticks to the mold, it will act as a sort of wedge between the mold and the barely frozen cast. If the slag does not actually stop the casting, it will finally go down between the mold and the cast and appear as a serious imperfection in the cast metal surface. This action is repeated as long as the slag accumulates on the surface of the metal. When slag is not present, the liquid steel meets the mold surface in the same way as the mercury in a barometer touches the glass, and is non-wetting. This problem has been solved reasonably well.

For reasons of economy, the minimum rate for casting all but the very costly steels must be several times as fast as for nonferrous metals. This high rate of casting, in conjunction with the adverse thermal properties of steel, made the problem of mold design difficult. Experiments have shown that to cope with these factors and to be amply safe, the mold must be designed with margin enough to withstand a steady stream of steel directed against it for an indefinite time and without damage to the mold. The Babcock & Wilcox mold, with this cooling ability, is absorbing heat where it contacts the hottest steel about 50 times as fast as in the hottest part of a high-duty modern boiler furnace. This is believed the highest thermal transfer rate in use for any purpose. To make this rate possible, water must flow across the outside surface of the mold at a velocity not much below a mile a minute.

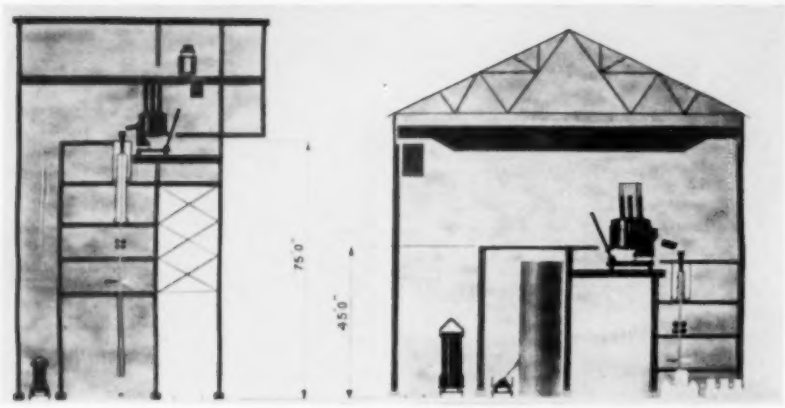
In continuously casting brass or other nonferrous metals by manual control, the operator is not prevented by radiation of heat or light from being as close to the work as necessary, because nonferrous metals may be conveyed through a metallic or refactory pipe, and their flow regulated by a hand-operated valve. With steel, it is impossible for a man to stay as near to the stream of metal as he must if regulation of rate of pouring and rate of extraction is to be left to his eyes and his hands. The radiation is too intense and beyond endurance as a daily task. A second reason for giving this job to a control mechanism is that even with a pouring



As the cast bar is withdrawn from the mold by pinch rollers, it is cut to length at this point. An oxygen lance is used for the cutting, riding down with the bar as it is withdrawn from the mold.

furnace as small as 5 tons, tipping it through an angle of 1 min of arc supplies enough steel for 18 sec of casting time. At the present casting rate this would be a change of level of 18 in., which is many times the allowable fluctuation of the metal level in the mold. Control of this relationship is more than a skillful man can manage for even a few minutes. As the pouring ladle or furnace, for commercial production, is likely to be 25 to 50 tons in size, completely automatic pouring is an absolute requirement before continuous casting of steel will make a significant change in the methods of the industry. By having the changing metal level in the mold occlude a shaped X-ray beam, which passes on through the mold to an ionization chamber, the ionization intensity change can be used to control the angular rate of tipping the furnace. The control mechanism for this purpose must not only control the overall relationship between the metal entering and leaving the mold, but also it must be able in a sufficient degree, to counteract hunting. That is, excessive alterations of the pouring rate.

It is natural that experimenters usually have tried to cast circular, square, or rectangular sections, which are the shapes now commonly rolled. However, as castings, there are grave objections to all three shapes. These objections arise mainly from the fact that steel freezes in two ways: Polyhedral grains and columnar grains are formed. In any form of freezing of steel, a large quantity of the impurities are forced into the boundaries between the grains, where they cause weakness. In polyhedral freezing, the random arrangement of the boundaries lessens the spread of cracking along



At left is the continuous casting setup of the Republic Steel Corp.-Babcock & Wilcox Tube Co. experimental plant. At right is shown a proposed plant for production of continuously cast steel shapes.

them, but the columnar grains, which grow perpendicular to the surface of the casting, have their long side parallel, and if a crack begins it can easily extend and become a serious defect.

The objections to the round section are that it has the least cooling surface for the most weight; that its time of freezing increases in direct proportion to its weight increase; and that the cold region near the surface acts like an arch trying to prevent shrinking as the interior cools, thereby causing it to deform and crack. These reasons suggest a flattened section with a much greater perimeter for its weight, and, on the average, a much smaller distance through which the heat must travel to escape. The square also cools slowly in direct proportion to its section, and its columnar pattern tends to form cracks. The rectangle, if not too long and narrow stands well in respect to rapid freezing as the heat has a short path of escape. However, the freezing pattern produces a plane of weakness, which may easily cause cracking.

An oval casting has two relatively pliable sides, yielding as the casting shrinks and avoiding cracking. It has a large surface to weight ratio, and therefore cools rapidly. The columnar grains grow at right angles to the surface near which they originate until they interfere with each other. They arrive near the central plane at different times and from different directions, so that the central plane is much less sharply defined than in a rectangle. Therefore, the casting is much stronger. Experimenting showed the value of the oval shape, but there are many ovals. To determine experimentally with steel which group of these ovals yields the most satisfactory casting would have been extremely slow and costly. This problem was solved by using a low temperature alloy with a freezing pattern and cracking tendencies like steel.

It would be difficult and inconvenient to make a mold long enough to solidify the steel completely. With the use of a mold of practical length, much of the interior of the casting is soft or molten when it leaves the mold. If the section is not supported, it will swell and crack. At economic casting speeds, this can occur for a considerable distance below the mold. Therefore a means somewhat similar to the mold itself must be used to keep the casting from swelling. Devices for this purpose have been developed.

If the various studies now being made in New England, for example, should result in showing that a local supply of scrap and the demand for steel products conveniently made from it are in reasonable balance, then it would seem that there is much to be said for beginning with scrap and leaving the relatively large financial and supply problems involved in full integration for some later time. In that case, continuous casting becomes of special interest.

Work to date would justify the construction of a plant for regular production, casting oval cross-sections with an area of 25 to 40 sq in. These castings would be suitable for rolling into stock from which bars, rods, wire, narrow width strip, and other products can be made.

A mold of about 100 sq in. is now being constructed and will be tested this year. It will make a casting suitably shaped to supply a continuous sheet mill for rolling widths up to about 26 in., which is the greatest width that can be handled in the Babcock & Wilcox casting building. The mold design is such that the finished mold can be enlarged without limitations to even greater widths. Upon completion of this development, continuous casting eventually could be applied to 25 to 30 pct of the industry's tonnage, whereas a plant making sections of less than 40 sq in. would account for only about 15 pct of the country's output. Therefore, it seems unwise to build plants of limited size range until it is determined how much larger cross-sections can be cast.

A process entailing a major change in any industry should not be undertaken on a commercial scale until it can be known in advance that it will be highly successful. This general rule applies with special force to the continuous casting of steel, because of the failure of earlier attempts. It is believed, however, that the most advantageous location and the most suitable product for a first plant can be determined and the plant can be built. By 1952 the low capital and high yield characteristics of this process, will be commercially proved to a point warranting its further and general extension in the steel industry.

Some Observations On The

Continuous Casting of Steel

ALONG with the developments in continuous casting at Babcock & Wilcox Tube Co., others have been working toward the same ends. Predating the investigations by Babcock and Wilcox, Irving Rossi, president of Continuous Metalcast Corp., New York, had worked out methods that are in regular production in many of the nonferrous industries and more recently in the continuous casting of steel at the Watervliet plant of Allegheny Ludlum Steel Corp.

Continuous Metalcast Corp. has built about 15 commercial machines that have cast between 2 million and 3 million tons of metal. The experience in the development of these machines has been somewhat different than the experience with the equipment now in operation at Babcock & Wilcox. The reason for this, Mr. Rossi pointed out, may have been because the problem of continuous casting steel was approached from the viewpoint of applying a process proved on nonferrous metals.

Steel, it is believed, can be cast with facility equal to that of nonferrous metals if approached from the standpoint that steel is simply another alloy to which already proved procedures apply.

Steel has been continuously cast for about a year at the Watervliet plant of Allegheny Ludlum Steel Corp. on two casting machines, one large and one small. While the operation has been on a pilot basis, Allegheny Ludlum now feels it has advanced to a point where the installation of continuous casting equipment for commercial production is justified, and such equipment will likely be installed. It has been reported that two production casting machines will be built.

Experience with steel casting at Watervliet has indicated that thermal conductivity is no limitation in the casting of steel or of any other metal insofar as it affects the problem of heat removal. It is not the intention to remove all of the heat from the metal, but only the super-heat and the heat of fusion. The bar may come out of the machine at 1800° or 1900°F. Because it is necessary to remove more Btu's in the solidification of aluminum, pound for pound, the problems of casting steel do not appear as complex as the problems in casting some of the difficult aluminum alloys.

Different alloys require different cooling and casting treatment, but with the cooling system employed by Continuous Metalcast Corp. adjustments can be made during operation to take care of problems presented by the different alloys.

Mr. Rossi claims to have found materials that will withstand the erosion and heat of steel. The Rossi mold is copper, with a very high thermal conductivity. Babcock & Wilcox uses a brass mold, with a lower thermal conductivity. The Continuous Metalcast Corp. process, it is claimed, seeks to increase the rate of heat removal in the mold, and various techniques have been developed. One is by increasing the copper-water contact area in the mold.

Scovill Mfg. Co. is casting a 2½ x 25½-in. bar at a rate of about 15 tons per hr. It is felt that the rate of casting nonferrous metals must be increased by two or three times to be economically feasible for casting steel. Mr. Rossi indicated that it was felt that Allegheny Ludlum is in a position today to cast steel commercially by the existing practice, and Continuous Metalcast Corp. would undertake to build and guarantee the operation of such machines at sizable casting rates.

While the thermal conductivity of steel is low compared to copper and while the limitation of the casting rate of any metal is the rate at which heat can be withdrawn from the metal, Mr. Rossi stated that no one has ever cast any metal continuously at a rate limited by that metal's thermal conductivity. This, Mr. Rossi stated, was evidenced by the fact that Babcock & Wilcox is able to remove heat from the steel so rapidly that the castings ruptured. This is heat removal at so high a rate that enormous casting rates would result if the casting was done in a manner so as to produce sound castings.

The limitation in achieving such a high casting rate is the relative inefficiency of the mold and the cooling system to harness the rate at which steel can

IRVING ROSSI is President of Continuous Metalcast Corp., New York. **The data contained in this article was presented orally at the Electric Furnace Conference, Dec. 7, 1950, at Pittsburgh.**

give up heat. It is not the low thermal conductivity of the steel itself. Methods are being sought to increase the heat absorption efficiency of the mold.

Continuous Metalcast Corp. has found other factors more pressing for solution than low thermal conductivity when trying to adapt continuous casting to steel production. One of these is adapting present melting practices to present rates of continuous casting, particularly to cast small cross-sectional shapes for elimination of the blooming operation. Experience indicates that there is no particular limitation in cross sectional shape of the casting. Currently, by the Continuous Metalcast Corp. method, small rectangular steel bars, 3 x 15 in., are being cast and these have excellent surfaces and excellent interiors.

A machine has just been completed for casting aluminum for Imperial Chemical Industries, Ltd., in England, and it is guaranteed to cast circular billets up to 20 in. diam and rolling slabs up to 10 x 48 in. in cross section. It is believed that the same sizes can be cast in steel, if desired.

The Continuous Metalcast Corp. casting machines employ a holding furnace into which metal is intermittently fed from the regular plant melting furnaces. This holding furnace is fed from one end and from the other end the metal is bottom-poured into the mold. One such machine has run for two months continuously, producing a great amount of metal. The metal was brass, but the same procedure is visualized for steel.

The metal is fed from the holding furnace into a copper mold that is water cooled. This mold is oscillated to increase its cooling efficiency. A pair of pinch rolls withdraw the solidified casting from the mold. Below the pinch rolls, cutoff equipment cuts the bar into convenient handling sizes. For nonferrous metals a flying saw is used, and a torch is employed for steel castings. The severed bars fall into a basket that lowers them onto a conveyor.

No electronic or television techniques are employed in the Continuous Metalcast Corp. method for controlling the metal. The operators stand beside brass casting machines, operating them a full shift, exposed to about the same amount of radiant heat as they would be in casting steel. The same method of operation is anticipated for steel casting as for brass casting. At Allegheny Ludlum, no serious radiant heat problems have been encountered.

The philosophy of Continuous Metalcast Corp. is to remove the maximum amount of heat from the metal in the mold and as rapidly as practical. The copper mold is 15 in. long, and still believed to be too long. The shell formed around the cast metal at the instant of contact of the molten metal with the mold becomes stronger as the metal further solidifies, and it shrinks away leaving an air space between the casting and the mold. This shrinkage is believed to take place within the first 2 to 4 in. The air space is a nonconductor. To increase the cooling or to use more of the mold than can be used ordinarily by the contact between the metal and the mold, water is introduced. Water is brought into the space between the casting and the mold. Steam does not result from this practice. In casting steel, water has been run up through this shrinkage space and even over the top of the mold. There was no explosion and the only steam formed was on the metal pool. The practice is the same in casting aluminum, brass, and copper.

The reason this is possible is that the thermal conductivity of the copper mold is so much greater than the thermal conductivity of the water that it loses its heat to the mold before the water has a chance to turn to steam. As water is a better heat conductor than air, more efficient cooling is obtained by this method. New methods and devices will ultimately result in increased casting rates while maintaining a sound metal structure.

Cascading metal into the mold results in a poor structure. Underpouring into the mold through a distributor permits a minimum metal velocity. Therefore, the hottest metal in the mold is at the top of the mold, and from there it loses heat constantly as it is withdrawn. In cascading, as in top pouring, the hottest metal is at the level at which the cascading metal loses momentum. This means the surface formed at the metal level is destroyed at a lower point, and reformed lower still.

Commenting on costs, Mr. Rossi indicated that in casting brass, continuous casting by the Continuous Metalcast Corp. method saves between $5 and $10 a ton over other methods of casting. Those savings result from elimination of butt ends, short pouring time, no mold maintenance, better quality, greater production per man-hr, and greater mold life. These figures were based on operations at Scovill Mfg. Co., where about a million tons of metal have been cast by this method. The new Scovill mill is based upon this direct casting method, and has two casting machines, one for slabs and one for billets.

Estimates of potential substantial savings made by the cost accountants of Allegheny Ludlum Steel Corp. and by an engineer engaged for the work are a major reason why Allegheny Ludlum has continued to push the development. The yield of finished product per ton of cast steel should run between 97 and 98 pct of the metal brought to the machine. Mr. Rossi stated that a steel round 4½ in. diam has been cast at the rate of 60 ipm, and with a new mold design it is believed that a slab 3 x 15 in. in cross section will be cast at a rate of 30 to 40 tons per hr.

The first machine installed at Scovill Mfg. Co., in 1938 was guaranteed to operate 168 hr without interruption at a rate of 7000 lb per hr casting a 7½ in. diam brass billet. Four operators from Germany erected the machine and carried out the test. The normal casting rate for this size billet has since increased from 7000 to 18,000 lb per hr, and Scovill agrees that this is not the limit in casting speed.

When the machine was first installed, it was supplied with metal by seven or eight 1000-lb melting furnaces. As the casting rate rose, it was necessary to increase the number of furnaces until the number of units made the operation unwieldy. Scovill doubled the furnace capacity to reduce the number.

Recently, with a casting rate of up to 30,000 lb per hr for slabs, furnace practice was again changed, and three Ajax-Scomet type induction furnaces were installed, each with a capacity of 10,000 lb of metal per hr.

Mr. Rossi feels that the first impact of continuous casting upon the steel industry will be to affect furnace size. An hour seems to be the maximum time allowable for casting of a single furnace charge if double handling and alloy changes are to be avoided. The ideal melt shop, therefore, is one in which the furnace capacities can be cast within an hour and in which the pouring intervals of the furnace can be synchronized with the casting rate. As casting rates increase, this will extend the adaptability of continuous casting to steel production.

El Paso Refinery Of Phelps Dodge Refining Corporation

by B. B. Kunkle

The history of this refinery has been one of expansion. It now has the capacity to produce 240,000 tons of cathodes annually. A general flowsheet and descriptions of the plant layout, operations involved, and equipment used at one of the world's largest and most modern electrolytic copper refineries are presented.

THE El Paso copper refinery of Phelps Dodge Refining Corp. was originally constructed by the Nichols Copper Co., in association with Phelps Dodge Corp. and the Calumet & Arizona Mining Co., in order to refine anode copper produced at the smelters of the two latter companies.

Initial production was obtained from the plant in January 1930 and its annual refining capacity was 100,000 tons of anodes.

In order to keep pace with Phelps Dodge Corp.'s increasing copper production in the Southwest, it became necessary in 1937 to increase the El Paso plant's refining capacity to 160,000 tons of cathodes annually. This was accomplished by adding two sections to the electrolytic tank house, increasing the number of anodes placed in each commercial electrolytic tank from 33 to 37, and making changes in the dc circuits which made it possible to put three generators on each of the two circuits instead of two, thus increasing the amperage on each circuit from 10,000 to 14,800 amp. The capacity of the two furnaces from which refined shapes were cast was increased by raising the sidedoor bays on the furnaces 6 in.

An increase of 70 pct in the productive capacity of Phelps Dodge Corp.'s Morenci Branch in 1942 again made it necessary to expand refining capacity. In order to accomplish this, Defense Plant Corp. set up a project to increase the capacity of the El Paso plant to 240,000 tons of cathodes annually. This project consisted of enlarging the tank house approximately 50 pct, the construction of another wire-bar furnace, and corresponding increases in other departments where necessary. The engineering work on this expansion was begun in March 1942. Actual construction was under way by August 1942, and the work was completed by March 1944. These additional facilities were purchased from Defense Plant Corp. by Phelps Dodge Refining Corp. in August 1949.

The plant is in El Paso about eight miles east of the center of the city and near Highway 80 and the main lines of the Southern Pacific and Texas & New Orleans railroads. The plant site covers approximately 494 acres of company-owned land that is ideally adapted for its use, being well-drained sandy soil and having enough slope so that a minimum amount of excavation was required when the plant was constructed. There is still ample room on the plant site for any future plant expansion.

The plant is constructed on four different ground levels and so arranged that the unrefined copper is unloaded on the highest level at the north side of the plant and the refined copper is shipped out from the lowest level on the south side of the plant. The receiving or unloading platform, weighing and sampling rooms, main floor of the tank house, acid and condensate storage tanks, and the slimes and copper sulphate plants are on the first or highest level. The tank house basement, yard scales, charging and furnace bays, balloon flue and stack, brick-storage building, substation and power house, boiler feedwater treating plant and pump house, water storage tanks, and change houses are on the second level. This second level also contains ample yard area for setting-up furnace charges, and for storage of custom scrap, cathodes, scrap anodes, blister, coke, and poles. The casting wheels, inspection conveyors, cathode shears, wire-bar scalping machine, slag

B. B. KUNKLE, Member AIME, is Plant Metallurgist, Phelps Dodge Refining Corp., El Paso, Texas.

Discussion of this paper, TP 3010D, may be sent (2 copies) to AIME by May 1, 1951. Manuscript, Oct. 2, 1950. St. Louis Meeting, February 1951.

This page of Metals Transactions AIME is a continuation from p. 180. The missing pages appeared in Journal of Metals.

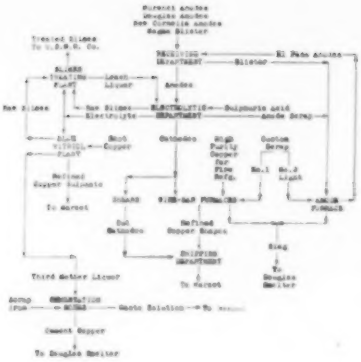


Fig. 1—Flowsheet of El Paso Refinery.

dump, and shipping department are on the third level. There is also a storage area on this third level, adjacent to the casting building, for storing moulds and refined shapes. The warehouse, machine shop, laboratories, engineering and administrative offices, personnel offices, first-aid station, water-cooling ponds and pump house, and parking lots for the employees are on the fourth or lowest level.

Transportation of materials into and out of the plant, except for the small amount trucked in, is by means of a main spur from the Southern Pacific railroad and six side spurs to various parts of the plant. Transportation of copper between the various departments in the plant is by means of a 30-in. gage track system using locomotives powered with electric motors or combustion engines. A general flowsheet of the plant is shown in Fig. 1.

Receiving and Sampling

The copper refined at the plant consists of anode copper produced at Phelps Dodge Corp.'s three smelters in Arizona, blister copper produced at Magma Copper Co.'s smelter in Arizona, and No. 1, No. 2, and Light custom scrap copper received from dealers throughout the western part of the United States.

All anode and blister copper is unloaded, weighed, and sampled by the receiving department. This copper is delivered to the plant in or on standard gage box or flat cars, these cars being spotted on a spur adjacent to and paralleling the receiving platform. The receiving platform, adjacent to the north side of the tank house, is approximately 662 ft long and 91 ft wide, and is paved with concrete. This area provides ample space for the six unloading stands, two 20-ton track scales, drilling and sampling rooms, and storage for anodes.

The anodes are unloaded, by means of hand trucks and air hoists, from the railroad cars into anode rack cars that hold the same number of anodes that are loaded into a commercial electrolytic tank. After the anodes are loaded into the anode rack cars, the net weight of the copper in each one is determined carefully. The cars containing the anodes that are not sampled are taken directly into the tank house for unloading into the electrolytic tanks, or unloaded and placed in stock according to requirements. The cars containing the anodes that are to be sampled are stored on tracks east of the drilling room in an area provided for that purpose. After these anodes have been drilled, they are handled in the same manner as the others.

Blister copper is unloaded by stacking it on the floor of the anode rack cars, about 50 pieces in each car. After weighing and sampling, this copper is delivered to the yard for unloading into storage or transferring to cathode flat cars for charging to the anode furnace.

The drilling room is equipped with air hoists for handling the copper and three drilling units. A separate room is provided for grinding, screening, quartering, and otherwise preparing the samples for the laboratory. All drilling is done according to carefully designed templates.

Custom Scrap

Custom scrap is received in a yard area east of the receiving department and is serviced by a standard gage railroad siding that also serves the blue vitriol plant. The copper scrap is unloaded on an area, 40x250 ft, paralleling the tracks and paved with reinforced concrete. An unpaved area to the east provides space for burning insulated wire.

After unloading, the copper scrap is sorted and classified according to the best established refinery practice. Only No. 1, No. 2, and Light copper is accepted. It is then sampled, baled, and weighed. No. 1 copper is charged to the wire-bar furnaces, and No. 2 and Light copper is charged to the anode furnace.

Electrolysis

The multiple-system tank house consists of one large room that has an east-west length of 775 ft and a north-south width of 328 ft, thus covering an area of nearly 6 acres. The building has red hollow-tile walls and a cast-gypsum roof, the top of the roof being protected with Barrett specification roofing. The walls and floor of the basement, as well as the main working floor, are concrete. The building has three monitors in the roof which extend the entire length of the building. The center monitor has 25 Robertson ventilators which provide natural ventilation. Large, continuous windows in both the walls and monitors provide ample natural light during the day. Hinged sections in these windows provide a means for greater ventilation during the summer months. The maximum, inside height of the monitors above the working floor is approximately 41 ft. The electrolytic tanks are separate from the working floor, and both are supported by concrete columns in the basement. The clearance between the basement floor and the working floor is approximately 7 ft.

There is one central pump bay 36 ft wide extending the entire length of the tank house. This bay has a maximum depth of approximately 15 ft below the level of the working floor and contains the sumps, pumps, head tanks, storage tanks, and other equipment required to handle the electrolyte and slimes.

There are two crane bays on each side of and parallel to the pump bay. Each of these four crane bays, which contain the electrolytic tanks, are 73 ft wide and are equipped with a total of seven overhead, two-hook cranes: namely, two 15-ton Shaw-Box cranes and five 12½-ton Milwaukee cranes. A No. 14 Bedford transfer crane, at the east end of the tank house, is provided for transferring cranes from

one crane bay to another. These cranes are used for placing anodes into and removing anode scrap and cathodes from the electrolytic tanks, stripping operations, and handling starting-sheets and suspension bars.

The electrolytic tanks are constructed of reinforced concrete 5 in. thick, adjacent tanks having a common wall, and they are lined with 8-lb, 6 pct antimonial lead. The inside dimensions of each tank, after the lead lining is in place, is about 13 ft 2¼ in. long, 43 in. wide, and 46 in. deep. Thirty-two, 2-in. fiber-conduit weep holes are spaced equally in the bottom of each tank so that leaks in the lead lining can be detected quickly. The tanks are supported by reinforced concrete columns capped with 1-in. thick glass plates.

There are 38 sections of 32 tanks each and 17 sections of 36 tanks each, making a total of 55 sections and 1828 electrolytic tanks. Normally, 52 sections having a total of 1728 tanks are used for producing commercial cathode copper, and 3 sections having a total of 100 tanks are used for producing starting-sheets. The 32 tank sections have two rows of 16 tanks each and the 36 tank sections have two rows of 18 tanks each. The commercial electrolytic tanks have a capacity of 37 anodes and 38 cathodes, the spacing between anodes is 4 in. The starting-sheet electrolytic tanks have a capacity of 34 anodes and 33 starting-sheet blanks, the spacing between anodes is 4½ in.

The Whitehead single-contact system is used and a Baltimore groove is cast in the top of the positive lug of each anode. Three electrical circuits are used: No. 1 consisting of 2 starting-sheet sections and 18 commercial sections, No. 2 consisting of 18 commercial sections, and No. 3 consisting of 1 starting-sheet section and 16 commercial sections. The average maximum current density used on each of the three circuits is about 20.5 amp per sq ft. The average voltage measured across each commercial section is about 6 v.

The electrolyte is separated into five separate circulations or liquor circuits. Two of these liquor circuits have 16 commercial sections on each of them, while the other three have 8 commercial, 8 commercial and 1 stripper, and 4 commercial and 2 stripper sections on them, respectively. A total of 15 Worthington centrifugal pumps are provided for pumping the electrolyte. Eight of these pumps are used normally for circulation purposes, three are standby pumps, and four are used for pumping into or out of storage tanks. Ten of the pumps are the vertical type and the balance are the horizontal type. The circulation of the electrolyte through the electrolytic tanks is from bottom to top in a longitudinal direction at an average rate of 4 to 5 gpm.

Seven, single-pass floating-head Karbate heaters made by the Chemical Equipment Manufacturing Co. have been installed recently to heat the electrolyte, the electrolyte passing through these heaters while it is being pumped from the sumps to the head tanks. These heaters consist of a bundle of tubes made of Karbate through which the electrolyte passes, the tubes are enclosed in a lead-lined steel shell into which steam is injected. The 1-in. diam lead-pipe coils in the sumps, formerly used for heating the electrolyte, are now used only for standby and occasionally auxiliary heating purposes. The temperature of the electrolyte in the head tanks is maintained at approximately 145°F.

The addition reagents added to the electrolyte consist of glue and sodium chloride. Excess copper is removed from the electrolyte by means of electrolytic tanks in the commercial sections loaded with insoluble lead instead of copper anodes. The free sulphuric acid content of the electrolyte is maintained by the additions of 66 Bé H_2SO_4 and distilled water. The amount of impurities in the electrolyte are controlled by withdrawing solution from the liquor circuits and sending it to the blue vitriol plant where it is used for making commercial grades of copper sulphate.

The electrolyte contains an average of about 3.5 pct Cu, 17.5 pct free H_2SO_4, and 0.0025 pct Cl. Sufficient addition reagents are added to the electrolyte to produce a smooth cathode that is not too hard.

The commercial anodes have a body 36 in. sq and weigh approximately 690 lb. Stripper anodes, cast in the El Paso refinery, have a body 38 in. wide and 37½ in. high, and weigh approximately 840 lb. Starting-sheets are 37½ in. sq and the average weight is about 11½ to 12 lb without the loop.

The average anode cycle is about 26 days. The average commercial cathode cycle is about 13 days. Starting-sheets are stripped daily.

Normally, the commercial sections are operated with one side charged with new anodes and the other side charged with half-run anodes. Thus, the anode scrap must be removed from one side of the section, the slimes cleaned out of the tanks, and new anodes loaded into them each time the cathodes are pulled from both sides. Anode scrap is pulled from one side of each stripper section every two weeks.

Starting-sheets are looped with a single loop 18 in. wide, threaded with a suspension bar, and placed in racks in the same areas where the stripping is done. The racks of starting-sheets then are placed on top of the sections where they are required. The sheets are flapped dry on stainless steel flapping boards and placed in the tanks by hand after the anodes are in place. This is the only flapping that is done. Metermen and hot-sheet men work daily on top of the sections eliminating the short circuits that occur between the anodes and cathodes.

Four cathode washing machines, two on each side of the pump bay, are in the basement. The cathodes are loaded into these washers with the cranes through openings in the working floor. Chain conveyors carry the cathodes in a vertical position through these washers while hot distilled water under high pressure is sprayed on them. When the cathodes are discharged from the washers, they fall in a flat position on cathode flat cars and are ready to be hauled to the yard for weighing.

Openings in the working floor also are provided for loading anode scrap, after it has been washed free of slimes, upon cathode flat cars in the basement so that it can be removed to the yard for weighing.

The tank house slimes, which contain the precious metals and other insoluble anode impurities, are collected in a separate launder system when they are cleaned from the electrolytic tanks. After screening through a 35-mesh screen, these slimes are pumped in the form of a slurry to storage tanks in the basement of the slimes treating plant.

Slimes Treating Plant

The building is 100 ft east of the tank house and consists of a 19x54-ft main building with four floors and a basement and a 38x39-ft south extension with a main floor and basement, the basements are on the same level as the tank house basement. The walls

are made of red hollow tile. The main building has air-tight windows made of glass blocks, the inside walls have a smooth coating of plaster, and the reinforced concrete floors are all sloped and provided with drains so they can be washed.

The main building is ventilated with a large blower. The suction of this blower is connected to pipes that extend to and have one or more openings on each floor. Dampers are located near each opening so that flow of air into them can be regulated. Air is drawn into the building on each floor through adjustable louvers in the walls. The air from the blower is discharged into a scrubber where any dust that may be in the air is removed with water before it is discharged to the outside. This method of ventilation prevents the loss of any dust.

Copper is present in the tank house slimes in the form of metallic copper and copper selenide and telluride. The purpose of the slimes treating plant is to reduce the copper content of the slimes to 3.0 pct or less. This is accomplished by aeration in tank house electrolyte.

The slimes slurry pumped from the tank house to the three storage tanks in the basement is allowed to settle. The clear liquor is returned to the tank house and the thickened slurry is pumped to tanks on the top floor of the building where further thickening is accomplished by settling and decantation. The resulting heavy slimes slurry is charged to four leaching tanks, on the same floor, that previously have been charged with tank house electrolyte. These lead-lined wooden tanks are about 6½ ft sq and 13 ft high. Air under 10-lb pressure is introduced into the bottom of each tank through 16 equally spaced ¼-in. diam orifices. Air is supplied with a Fuller rotary air compressor. The charge is heated with live-steam jets. After leaching is completed, the leached slimes again are thickened and then washed free of electrolyte by settling and decantation in five tanks located on the 3rd floor and 2nd floor mezzanine. These slimes then are filtered on a 3x4-ft Oliver drum filter that discharges directly upon a gas-fired Lowden drier, with a 4x27-ft hearth, located on the 2nd floor. The leached slimes are dried to about 10 pct moisture before being discharged into a tilting double-cone mixer, on the 1st floor, from which they are dumped, sampled, and then packaged in iron drums.

All of the liquor from the leaching operations is returned to the tank house after it has been processed to remove small amounts of selenium and tellurium which go into solution. This is a cementation process using tank house stripper scrap.

The packaged slimes are shipped to the United States Metals Refining Co., Carteret, N. J., for further treatment.

Blue Vitriol Plant

This plant not only provides a means for purifying the tank house electrolyte, but also is capable of producing more than 1100 tons per month of copper sulphate that will assay not less than 99.0 pct $CuSO_4 \cdot 5H_2O$.

The building is north of and adjacent to the slimes treating plant. It consists of a 54x115-ft main building with three floors and a basement, a main floor 47x134-ft west extension, a main floor 16x77-ft east extension, and a 40x100-ft quonset storage building. On the north side of the plant is a 15x149-ft shipping platform serviced by a standard gage railroad siding. The walls of the main building are made of red hollow tile, and the two extensions have R.P.M. siding. All floors are reinforced concrete.

The electrolyte withdrawn from the tank house is stored in two storage tanks in the basement. This electrolyte is pumped to two oxidizing units on the 3rd floor. Each unit consists of two lead-lined steel towers for shot copper elevated so they will drain into a single charge tank. A charge to each unit amounts to about 52,000 lb of electrolyte. The solution is withdrawn intermittently from the charge tank and sprayed into the top of the shot towers, that are filled with shot copper, by means of an air lift operating under a maximum pressure of about 65 lb. Air is blown up through the shot copper under a pressure of about 4 lb. The solution drains down through the shot copper and back into the charge tank. The solution is heated in the charge tank with live-steam jets and circulated in the above manner until the free acid has been neutralized by converting it to copper sulphate, this usually requires about 12 hr per charge. This charge is pumped to a holding tank on the 3rd floor from which it flows by gravity to a filter press on the 2nd floor where the float slimes are removed. The filtered liquor is pumped to one of five atmospheric evaporators on the 3rd floor where it is evaporated to about 49 Bé. Each evaporator is equipped with eight double 100-ft steam coils made of 1-in. diam lead pipe which are operated under 30 lb pressure. Then this liquor is put into atmospheric coolers, one charge from an oxidizer unit ultimately filling a cooler.

The coolers are lead-lined steel tanks. The inside dimensions are about 7½x16½x4½ ft with ends curved on a radius of 3¾ ft and they have a working capacity of about 500 cu ft. There are 16 coolers on the 2nd floor and 15 coolers on the main floor west extension. A total of 180, ¾x48-in. round copper rods are spaced equally and suspended vertically in each cooler on 2x4-in. boards supported by iron tee bars. A drain in the form of a plug seat is provided in the center of each cooler bottom.

The coolers are operated normally on either a six or seven day cycle depending upon production demands, and each cooler will produce an average of about 8 tons of copper sulphate per cycle. About one day of each cycle is required for draining the cooler, cleaning out the copper sulphate crystals that form on the rods, sides, and bottom, and refilling it. When the crystals are removed from the coolers, they are placed in 30-in. gage side-dump cars of about 3000-lb capacity, trammed by hand to a 6000-lb capacity elevator, and taken to the 3rd floor where they are dumped through grizzlies into storage bins, the bottom crystals being kept separate from the rods and sides crystals. The sides and rods crystals are crushed with a finger crusher, screened through a 3x8-ft vibrating triple-deck Niagara screen located on the 2nd floor, in order to separate or grade the crystals according to size, and stored in bins on the main floor from which they are bagged. The bottom crystals are crushed with a saw-tooth crusher, washed and centrifuged dry, and blended with the other crystals on the screens. The bagged crystals are handled and stored on wooden pallets by using a Clark fork-lift truck.

First mother liquors are evaporated to make second crystals, which are also of commercial grade. Second mother liquors are evaporated to make third crystals, which are dissolved with distilled water in an agitator and the solution returned to the oxidizing units. Third mother liquors are sent to cementa-

tion tanks where the copper that remains in solution is removed with iron. The waste liquor is discarded and the cement copper sent to the Phelps Dodge smelter at Douglas, Ariz.

The east main floor extension houses a Raymond No. 32 impact pulverizer equipped with a drier fired with natural gas, cyclone collector, mechanical separator, and Dracco collector. This equipment will convert about 600 lb of blue vitriol per hour into —300-mesh Instant or Monohydrate copper sulphate.

Shot copper for the process is produced at the Douglas smelter from converter copper. It is received in railroad box cars and unloaded through hatches on the shipping platform into storage bins, located in the blue vitriol plant basement. It is trammed to the top of the shot towers by means of bottom-dump 30-in. gage cars and a 5000-lb capacity elevator.

Casting and Inspection

The building, which houses the casting, inspection and shipping departments, and also the cathode shears and wire-bar scalping machine, is 479 ft long and 207 ft wide and is directly south of the tank house, the charging floor being on the same level as the tank house basement. The intervening yard space, which is 220 ft wide, provides ample room for the two yard scales and setting-up furnace charges. The building has two levels: Namely, the charging and furnace level, and a casting, inspection, shipping, shearing, and scalping level, the difference in elevation is 7 ft. The sides of the building are covered with Tennessee galvanized copper-steel sheathing and the roof is cast gypsum except for the metal roofing directly over the furnaces.

The charging bay is 40 ft wide and is equipped with two 3½-ton Morgan overhead charging cranes and one 5-ton Milwaukee overhead service crane. The pole storage area is outside of the building at the east end of the charging bay. The furnace bay is 24 ft wide. The reverberatory anode furnace has a capacity of 225 tons and is equipped with a 600-hp waste-heat boiler. Two wire-bar furnaces have a capacity of 385 tons each and are equipped with 600-hp waste-heat boilers. A third wire-bar furnace has a capacity of 400 tons and is equipped with a 1200-hp waste-heat boiler.

Anode and wire-bar furnaces have inverted-arch, silica brick bottoms; hard-burned magnesite brick below the metal line; chemically bonded brick in back wall, throat, and uptake; and 15-in. silica brick in the hood and main roof. The verb arch and the supporting arch for the uptake are of magnesite-chrome mixture brick. The buckstays at the charging side are protected by steel water-cooled pads. At the charging doors, two on the anode and three on the wire-bar furnaces, the buckstays are protected from the furnace heat, when the doors are open, by heavy castings bolted to the buckstays. The charging doors, which are water-cooled on the sides and bottom, are lined with fire brick and operated by air hoists. Water-cooled flange steel skewbacks are used on the charging side of the furnaces and cast iron skewbacks on the back wall side. All water used for skewbacks is treated with Calgon and this has minimized scale and skewback failures.

Natural gas, which is used for fuel, is delivered to the plant at 350-lb pressure, is reduced to 35 lb in the meter house and is at about 30 lb when it reaches the furnaces. The anode furnace and two of the wire-bar furnaces are equipped with Coppus-Dennis burners, two on the anode and three on the wire-bar furnaces. The third wire-bar furnace is equipped with three Tate-Jones, cement-kiln type, low-pressure burners. Two wire-bar furnaces have pre-heaters for raising the temperature of the air for combustion. The combustion air from two 10,000 cu ft forced-draft fans passes through carborundum tubes which are heated by the combustion gases passing around these tubes on their way to the main balloon flue and 410-ft stack. The anode and one wire-bar furnace have bypass or auxiliary stacks that have a height of 78 and 91 ft, respectively, above the charging floor.

The casting and inspection bay, 67½ ft wide, is serviced with two 15-ton overhead Milwaukee cranes and one 15-ton overhead Shaw-Box crane.

Anodes are cast in 20 copper moulds on a 31-ft diam Clark wheel with a single ladle that is controlled electrically. Pulverized silica, 200 mesh, is used to paint the moulds. The copper insert blocks for the Baltimore groove are cast by the furnace crew. Two push pins activated by a toggle arrangement raise the anodes from the moulds. A ½-ton Shaw bosh crane removes the anodes from the moulds and places them on spaced racks in the bosh. An overhead crane removes the anodes from the bosh with a rack similar to the rack used in the tank house. After inspection, the anodes are placed in an anode rack car and transported to the receiving department for weighing and sampling before they are stocked or delivered to the tank house.

Wire bars, ingot bars, and ingots are cast on three 40-ft diam Clark wheels, each having 30 copper moulds and using two ladles, all of which are controlled electrically. The moulds are painted by spraying a water and bone ash emulsion with high-pressure air. The moulds are turned over by means of a dumping-tee mechanism and the cast shapes fall into a bosh pit where they are quenched. An incline conveyor brings the cast shapes up out of the bosh pit to an inspection conveyor where the copper inspectors gage each piece for size and make a rigid inspection for defects. The wire bars are removed from the inspection conveyor with air hoists and loaded on cars which are delivered to the shipping department. Ingot bars and ingots are removed from the inspection conveyor by hand and placed on wooden pallets which are delivered by powered fork-lift trucks to the shipping department. Rejected pieces are placed to one side for remelting.

A mould press on each wire-bar furnace having water-cooled copper wire-bar dies is used to make the copper moulds required for the various sizes of wire bars. A portable tilting ladle is used to cast anode moulds.

A charge for the anode furnace consists of anode scrap from the tank house, blister, ladle scrap, and No. 2 and Light custom scrap. A wire-bar furnace charge consists of cathodes, No. 1 custom scrap, ladle scrap, moulds, warmers, and rejects. The furnaces are operated on a 24-hr cycle. This cycle, which begins early in the afternoon, consists of charging, melting, skimming slag, flapping, covering charge with coke, poling until the copper has reached the required set, and casting the copper into shapes. Flapping is done with iron pipes using air under 20-lb pressure. Poling is with green, hardwood poles.

Fire-refined copper cast into ingots and ingot bars is produced from the wire-bar furnaces by charging

them with carefully selected high-purity copper.

Samples are taken of the castings from all furnace charges and analyses made for Cu, Ag, Au, and impurities. The conductivity of the copper is also determined.

Slags are broken up and stored in an outdoor area at the east end of the shipping bay. They are shipped in gondola cars to the Douglas smelter. Moulds are stored in an outdoor area 82 ft long at the west end of the casting and inspection bay which is serviced by the overhead crane in the west end of this bay.

A building at the eastern end of the yard area between the tank house basement and the charging floor provides storage facilities for stocks of brick, fire clay, silica, bone ash, charcoal, and other supplies for the anode and wire-bar furnaces. This building is of hollow tile construction and is 39x260 ft. A standard gage railroad siding parallels the south side of the building. Coke is stored in an open area east of this building.

A brick-grinding plant, just east of the furnace bay, is equipped with a jaw crusher, Gruendler grinder, Raymond impact pulverizer, and a bag-type dust collector. This equipment is used to grind silica, magnesite, and chrome brick cobbings for furnace repairs.

Shipping

The shipping bay, south of and adjacent to the casting and inspection bay, extends the full length of the building and is 60 ft wide. This, together with an outside storage area of the same width and 165 ft long, at the west end of the bay, provides ample storage for refined shapes. This bay and storage area is serviced with one Euclid, one P & H, and one Milwaukee overhead crane, each having a capacity of 10 tons. Three track scales of 20-ton capacity each are provided for weighing copper. Two "Ready Power" motor-powered trucks and three Baker trucks powered with Edison batteries, all of which are the fork-lift type, are used for handling palletized ingots and ingot bars and for loading all kinds of refined shapes into railroad cars. A shipping platform 15½ ft wide and 594 ft long is parallel with and adjacent to the south side of the shipping bay and outside storage area.

Cathode Shears and Scalping Machine

Two Hilles-Jones shears for shearing cathodes are at the east end of the shipping bay. Each shear consists of a large shear for cutting off loops and making the first cut and a small cut-off shear which makes the final cuts. When producing 12⅝x17½-in. cathodes, each shear will cut 220,000 lb of cathodes per 8-hr shift.

An Ingersoll single head, custom built, scalping machine is also in the shipping bay. This machine will scalp 275—54-in.—wire bars per 8-hr shift. Just enough copper is cut from the set side of the wire bars to remove the roughness which is characteristic and appears at this surface.

Warehouse and Shops

The warehouse is 69 ft south of the eastern portion of the shipping platform and is of hollow-tile construction. It consists of a building 39x240 ft with an unloading platform 15x220 ft serviced by a standard gage railroad siding.

The shops are 31 ft south of the western portion of the shipping platform and 80 ft west of the warehouse. The building is of hollow-tile construction, is 57x280 ft, and houses the machine, blacksmith, electrical, and carpenter shops equipped with the machines and tools necessary for the maintenance of a plant of this type.

Power

All of the electric power for the plant is purchased from the El Paso Electric Co. Alternating current is delivered at 13,200 v and stepped down to 2300 v at the plant substation.

A brick building, 51x144 ft, with the main floor 15 ft above the ground floor, houses the direct-current power generating equipment for electrolysis. The air-conditioning and armature-cooling equipment, bus bars, and switchgear are on the ground floor. The motor-generator sets, control equipment, and four air compressors are on the elevated main floor. This floor is serviced with a 15-ton Bedford overhead crane, and an open bay at the east end of the building facilitates the removal and installation of heavy equipment. The building is located centrally 73 ft south of the tank house.

Direct current is produced with three double unit and two triple unit General Electric motor-generator sets, each dc generator unit having a capacity of 750 kw and an output of 5000 amp at 150 v. A full tank house requires the operation of two double and two triple sets, as each of the three electrical circuits in the tank house require nearly 15,000 amp. The other double set is held as a standby. Except for the motor-generator sets, which operate on 2300 v, practically all of the electric motors in the plant are operated on 440 v. A standard 220-110 v, three wire, single-phase lighting system is used.

The four Ingersoll-Rand air compressors supply compressed air for general plant requirements. Two of these are low-pressure compressors, each having a capacity of 1080 cfm at 40 psi. The other two are high-pressure compressors, each having a capacity of 1210 cfm at 100 psi.

Water Supply and Treatment

All of the water required for plant operations is obtained from three 700-ft water wells equipped with Layne-Texas turbine-type pumps. These pumps deliver water to three tanks having a total capacity of one million gallons. Two of these tanks are elevated in order to maintain about 30-lb pressure in all of the fresh water lines. An electrically driven pump and one driven with an internal-combustion engine, which is used in case of a power failure, boost the pressure in the water lines to as much as 125 lb for fire-fighting purposes.

All of the water pumped from the three wells is given the Hall Threshold treatment. The boiler feedwater is treated by the Infilco hot lime-soda ash and the Hall system.

General

The general office building, west of the shops near the main plant entrance, houses the administrative, accounting, and engineering offices, and a well-equipped laboratory.

Another building, at the main plant entrance, houses the time-clock alley, personnel and safety engineering offices, and clinic for first-aid treatment.

References

[1] Frank R. Corwin and C. S. Harloff: El Paso Refinery of the Nichols Copper Company. *Mining and Metallurgy* (1930) **11**, pp. 459-465.

[2] Expanded Copper Refinery. *Mining World* (Sept. 1945) **7**, No. 10, pp. 15-20.

Sulphur Activities in Liquid Copper Sulphides

by R. Schuhmann, Jr. and O. W. Moles

An equilibrium study was made of the reaction:

$$Cu_2S\ (liquid) + H_2\ (gas) \rightarrow Cu\ (dissolved) + H_2S\ (gas)$$

at temperatures of 1150°, 1250°, and 1350°C for liquid copper sulphides ranging in composition from saturation with Cu to about 21.5 pct S. From the experimental data, activities of Cu, S, and Cu_2S in the melts were calculated. Also, the results furnish a new determination of the location of the curve showing the compositions of Cu-saturated sulphide melts in the Cu-S constitution diagram.

THE "white metal" made as an intermediate product in converting copper matte to blister copper is a matte approximating Cu_2S in composition. It has long been known that liquid Cu-S mattes can exist at a given temperature over an appreciable composition range, with S:Cu ratios ranging up from a lower limit corresponding to equilibrium of the matte with a liquid Cu phase. The Cu-saturated matte has somewhat less S than Cu_2S, although previous measurements of the compositions of Cu-saturated mattes are not in good agreement.[1-4] As the S:Cu ratio approaches and slightly exceeds that for Cu_2S, the partial pressure of sulphur gas over the liquid matte rapidly approaches atmospheric pressure,[5] so that Cu-S melts with much more S than Cu_2S can be made and handled only in pressure apparatus. Accordingly, the liquid copper sulphides of interest in copper smelting and readily studied experimentally fall in a relatively narrow composition range about Cu_2S. The freezing points of Cu-S mattes show a maximum of 1129°C near the composition Cu_2S, dropping to 1105°C for Cu-saturated mattes having less S and dropping under 1100°C for higher S mattes.[4]

Estimates of the sulphur pressure and other thermodynamic properties of liquid Cu_2S were made by Kelley,[6] based on extrapolations from equilibrium measurements on solid Cu_2S. More recently, Cox and coworkers[7] studied equilibria in the reaction:

$$Cu_2S + H_2 \rightleftarrows 2Cu + H_2S$$

over the temperature range 700° to 1250°C. They measured equilibrium H_2S:H_2 ratios presumably with both the sulphide and the metal phase present, so that their data above the melting point of Cu_2S should measure the S pressure of Cu-saturated sulphide melts. The sulphur pressures of liquid copper sulphides of several S:Cu ratios at their freezing points can be estimated from data given by Posnjak, Allen, and Merwin.[5] However, beyond these few data, no systematic study seems to have been made of the relations of sulphur pressure and other chemical properties of liquid copper sulphides to composition and temperature.

The measurements of the sulphur pressures of liquid copper sulphides reported in this paper represent a first step in the quantitative study of the chemistry of mattes. Similar work is planned on

R. SCHUHMANN, JR., Member AIME, is Associate Professor of Process Metallurgy, Massachusetts Institute of Technology, Cambridge; and O. W. MOLES, Student Associate AIME, is associated with American Smelting and Refining Co., Barber, N. J.

Discussion of this paper, TP 3030D, may be sent to AIME by May 1, 1951. Manuscript, Nov. 9, 1950. St. Louis Meeting, February 1951.

This paper represents part of a thesis by O. W. Moles submitted in partial fulfillment of requirements for the degree of Doctor of Science to the Faculty, Massachusetts Institute of Technology.

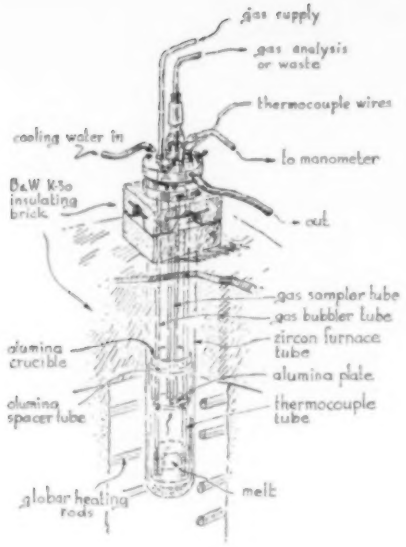


Fig. 1—Furnace tube assembly.

Cu-Fe-S mattes and on mattes containing oxygen. The relationship of these studies to other aspects of copper-smelting chemistry was discussed in an earlier paper by one of the authors.[5]

The experimental work of the present investigation consisted of measurements of H_2S:H_2 ratios for gas mixtures in equilibrium with liquid copper sulphides. These measurements were made for melts of varying S content, from Cu-saturation to compositions having the highest S activities conveniently determinable with H_2S/H_2 mixtures. The actual composition range covered was about from 19.5 to 21.5 pct S (balance Cu) and the temperature range was from 1150° to 1350°C. In addition, equilibrium H_2S:H_2 ratios were determined for systems containing the two mutually saturated phases, liquid Cu and liquid Cu_2S. From the experimental data, calculations were made of the S_2 pressures and of the activities of Cu and Cu_2S. Also the data furnished a new determination of the curve showing the compositions of Cu-saturated copper sulphides in the Cu-S equilibrium diagram.

Experimental Methods

The general procedure of equilibrium measurement was as follows: A controlled mixture of H_2S and H_2 was bubbled through the Cu-S melt in a closed furnace system. Analyses were made of the entrant and exit gases. The composition of the entrant gas mixture was adjusted until the H_2S:H_2 ratios in entrant and exit gases were equal and remained equal for several hours. The final H_2S:H_2 ratio thus found was considered to be the equilibrium ratio. After equilibrium was established in this way, samples of the melt were taken and analyzed chemically for S and Cu.

Table I. Reproducibility of Gas Analyses

H_2S, Pct									
A	B	C	D	E	F	G	H	I	J
1.010	0.451	1.59	1.02	2.51	5.01	0.501	0.364	0.424	1.531
1.024	0.448	1.62	1.04	2.51	5.03	0.510	0.361	0.416	1.545
1.002	0.441	1.60	1.04	2.51	5.00	0.500	0.362	0.419	1.539
					5.03	0.488	0.355		
						0.498	0.363		
						0.496			

Furnace Arrangement: Fig. 1 shows the principal features of the furnace arrangement. The furnace tube was a zircon tube, 20 in. long x 3 in. in diam outside, with one end closed (test tube shape). This tube was suspended vertically in a Globar furnace, with the bottom of the tube just below the thermal center of the furnace and the top projecting through the top of the furnace. The mouth of the furnace tube was closed with a brass, water-cooled head provided with openings for sealing in the various gas inlet and exit tubes and the thermocouple protection tube. This assembly was substantially gas tight at operating temperature.

The principal parts inside the furnace tube were all of high quality alumina, and the crucible, protection tubes, and gas tubes were made of pure dense alumina (Norton Co.). The space above the crucible was filled with hollow alumina pellets as insulating material. The crucible was 2x8 in. and normally contained a melt of about 250 g which filled it to a depth of about 1 in. No chemical attack or penetration of the crucible or other parts by the melt was found, and in six weeks' continuous operation at 1150° to 1350°C the only deterioration in the system was erosion of the lower end of the bubbling tube. Referring to Fig. 1, the normal path of gas flow was into the crucible through the bubbler tube and then out through the gas sampler tube. For initial flushing of the furnace tube as a whole, however, the gas was taken out through a connection in the brass head, labeled "to manometer" in Fig. 1. The normal gas flow rate into the system was 120 ml per min.

The furnace was constructed of K-30 insulating bricks in a sheet steel shell, and measured 8 in. sq x 13½ in. high inside. Eight ½-in. Globar elements furnished the heat. A Rayotube sighted through a peephole onto the zircon furnace tube was connected to a Micromax recorder-controller panel with a Leeds and Northrup position-adjusting control unit. The control unit in turn was connected to a Leeds and Northrup valve-operating mechanism mounted on a General Electric induction regulator to control automatically the power input to the furnace. With this arrangement, furnace temperatures readily were maintained constant for long periods to within about 2°C.

Melt temperatures were measured with Pt—Pt-Rh thermocouples calibrated at the gold point by the wire-bridge method. Final equilibrium temperatures were checked with two couples, each inserted in turn into the bottom of the protection tube in the melt, as shown in Fig. 1. The maximum difference between the two couples was 2°C, and most of the duplicate readings checked within 1°C.

H_2S/H_2 Mixtures: The gas mixtures fed to the furnace ranged from 0.3 to 100 pct H_2S, the balance H_2. The H_2S and H_2 passed from their supply tanks through separate purification trains and flowmeters before mixing. The H_2 (electrolytic) was passed over a palladium catalyst and then through calcium sul-

phate and phosphorus pentoxide drying tubes. The H_2S (Matheson, 99.9 pct) was simply dried over phosphorus pentoxide. Constant composition of the gas mixture was obtained by automatically maintaining constant pressure drops across the flowmeters, using three bubbler-type pressure regulators, one upstream of each flowmeter and one on the mixed gas downstream from both flowmeters. Sized glass powders, compacted and sintered in glass tubes, were used for flow resistances in the flowmeters. Dow-Corning 550 silicone oil was used in the manometers and pressure regulators so that the system could be dried thoroughly. The gas trains were of all glass construction, except for short connections at the supply tanks and furnace.

Gas Analyses: The H_2S/H_2 gas mixture entering and leaving the furnace was analyzed by a method based on the fractional distillation of H_2 from H_2S in vacuum at liquid nitrogen temperatures. The analytical apparatus is shown in Fig. 2. The procedure was as follows: Evacuate the bulb; collect a sample in the bulb, preferably flushing with at least 10 volumes of gas, about 1 liter, to bring the glass and stopcock grease to equilibrium with the sample; measure the pressure and temperature of the H_2S/H_2 mixture; freeze the H_2S by immersing the bulb in liquid nitrogen and pump off the hydrogen, to less than 10 microns pressure; close the bulb, evaporate the H_2S, and return it to the original temperature of the gas mixture; measure the pressure of the H_2S, which is the partial pressure of the H_2S in the original gas mixture. For low percentages of H_2S, the H_2S was compressed into the smaller bulb before measuring its pressure. The ratio of the volume of the small bulb to the total volume of the two bulbs was determined by a calibration using H_2S. Corrections were made for the nonideality of the gases.

In developing this analytical method, a variety of tests were carried out. One check of the accuracy of the procedure consisted in analyzing known mixtures prepared in the bulb by admitting pure H_2 and H_2S successively, measuring the pressure after each addition. Another series of tests showed that no H_2S was lost after repeated freezing with liquid nitrogen and evacuation. Table I gives the results of repeated check analysis for ten different gas compositions ranging from 0.36 to 5 pct H_2S and shows the good reproducibility obtained.

Sampling and Analyses of Melts: Melts were sampled using 7 mm vycor tubing with the sampling end closed to the size of a pinhole. The sampling tube was lowered into the furnace after removing the gas sampling tube. Gas was slowly drawn up through the tube to flush out air. The end was then lowered into the melt and a sample sucked into the tube. Each time 10 to 25 g were secured. For two-phase melts, the gas bubbler tube was raised and the melt allowed to settle an hour before sampling.

All samples were chemically analyzed for both copper and sulphur. The electrolytic method was used for copper. Allen and Bishop's[8] method, involving weighing the sulphur as barium sulphate, was used for sulphur. Difficulties were encountered in obtaining the precision desired in the sulphur determinations, so that on some samples several repeats were necessary to obtain checks. In the end, the sulphur figures obtained by duplicate chemical analyses were checked against the copper analyses (by difference) and, for sulphur contents below

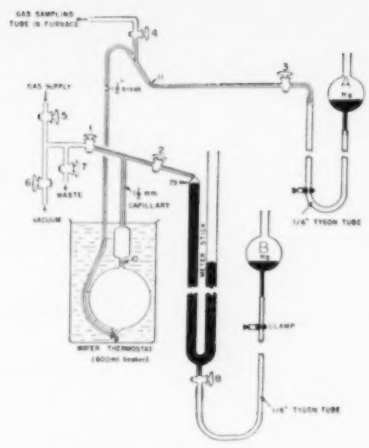


Fig. 2—Gas analysis apparatus.

20.14 pct (pure Cu_2S), were checked against analyses made by a pycnometer method.

R_2O_3 analyses on eight melts varied from 0.026 to 0.077 pct, averaging 0.048 pct. Iron analyses of six melts varied from 0.008 to 0.029 pct (R_2O_3 includes Fe_2O_3). These data showed the absence of melt contamination by the refractories.

Materials: A supply of high-purity copper was furnished by the Central Research Laboratory of the American Smelting and Refining Co. and analyzed as follows: 0.0015 pct Fe, 0.001 pct Sb, 0.0009 pct Pb, 0.0003 pct Sn, 0.0015 pct Ni, 0.00009 pct Bi, 0.001 pct As, and 0.0002 pct Te. A stock of copper sulphide was prepared by treating pieces of this copper with precipitated sulphur (U.S.P., Mallinckrodt) in a casserole heated over a laboratory burner. No precautions were taken to exclude oxygen, since any oxygen was removed as H_2O during the early stages of treatment with H_2S/H_2 mixtures in the furnace. The stock copper sulphide analyzed 78.5 pct Cu.

Experimental Results and Calculations

Blank Runs: Since comparison of entrant and exit gas compositions was used as the criterion of gas-melt equilibrium, it was necessary to establish the absence of side reactions in the furnace system. Accordingly, a number of runs were made passing various H_2S/H_2 mixtures through the complete furnace system at temperature, but without copper sulphide in the crucible. Results of these preliminary runs may be summarized as follows:

1—A newly assembled furnace system required a break-in period of several days passing H_2S/H_2 mixtures at temperature. During this period some H_2O was present in the exit gas. Also the $H_2S:H_2$ ratio was lower in the exit gas, indicating some accumulation of sulphur in the furnace parts.

2—After the break-in period, from 8 to 24 hr operation was required to bring the furnace to equilibrium with the gas after a major change in entrant gas composition.

3—To obtain equality of entrant and exit gas compositions, all the exit gas had to be removed

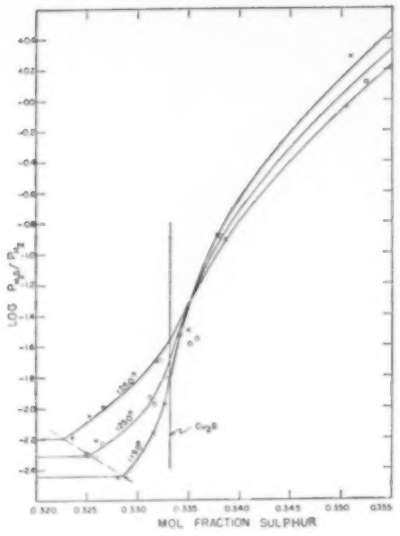


Fig. 3—Log P_{H_2S}/P_{H_2} vs. mol fraction sulphur at 1150°, 1250°, and 1350°C.

from the hot zone in the crucible through the gas sampling tube, shown in Fig. 1. When part was removed this way and part through the tube in the top of the furnace, to obtain quicker flushing, thermal separation took place so that the gas removed from the hotter zone was lower in H_2S than the ingoing gas.

The preliminary runs also indirectly shed some light on the effects of the dissociation of H_2S in the furnace. Within the crucible it is to be expected that equilibrium will be established in the dissociation reaction, $H_2S = \frac{1}{2}S_2 + H_2$. The entering gas mixture contained only H_2S and H_2, so that the S_2 must be furnished by dissociation of H_2S with a resultant change in the H_2S:H_2 ratio. For this reason, the H_2S:H_2 ratios measured by analysis at room temperature had to be corrected for dissociation to obtain the equilibrium values of the H_2S:H_2 ratios for the furnace conditions. However, the question arises as to what happened to the gas flowing out the exit tube. The hot gas entering this tube presumably was an equilibrium mixture of H_2, H_2S, and S_2. The absence of appreciable sulphur deposition in the colder parts of the gas exit, together with the fact that in the preliminary runs equality of H_2S:H_2 ratios was obtained between entrant and exit gases, indicated that very high reaction rates were obtained so that the S_2 recombined with H_2 in the short time of passage of the gas through the exit tube. This behavior was essential if a comparison of entrant and exit gas analyses was to serve as the criterion of equilibrium. When the H_2S content of the entrant gas was increased to 100 pct for the final equilibrium runs on high sulphur melts, however, appreciable sulphur deposition occurred and the exit gas never reached 100 pct H_2S, although it appeared from other grounds that gas-melt equilibrium had been established in the crucible.

Equilibrium Measurements: In all, 32 equilibrium determinations were made, the first four in one continuous run lasting ten days and the remaining 28 in a second run lasting six weeks. Each determination involved many gas analyses and adjustments of ingoing gas composition to find the equilibrium condition. After adjustments appeared to be completed in each determination, bubbling was continued for several hours with additional gas analyses to check the existence of equilibrium before taking final samples of the melt. A number of the equilibrium gas analyses were approached from both sides. From the general behavior of the system, it appeared that gas-melt reaction was very rapid so that the rather long time spent in reaching equilibrium after a change was needed mainly to bring the furnace

Table II. Experimental Data

Point No.	Time of Sampling, Hr*	Temperature, °C	Final Gas Analyses, Pct H_2S In	Final Gas Analyses, Pct H_2S Out	Melt Analyses, Wt Pct Cu	Melt Analyses, Wt Pct S	
Run I							
200 g Cu_2S stock charged at the start							
1	28	1296	2.05	2.04	79.74	20.06	
2	58	1236	1.63	1.63	79.76	20.09	
50 g Cu_2S added							
3	198	1154	1.049	1.061	79.77	20.06	
5 g Cu added							
4	246	1155	0.704	0.691	79.73	19.95	
Access tube broken. Furnace shut down.							
Run II							
250 g Cu_2S charged							
5	27	1243	2.94	2.92	79.73	20.18	
6	92	1243	2.78	2.77	79.62	20.30	
7	136	1243	2.56	2.54	79.67	20.25	
5.7 g Cu added							
8	265	1249	1.018	1.041	79.98	20.02	
4.8 g Cu added							
9	289	1251	0.587	0.587	80.33	19.64	
5.5 g Cu added							
10	377	1253	0.527	0.506			Two liquid phases in
5.2 g Cu added							
11	427	1253	0.522	0.509	80.28	19.49	crucible; analyses are
100 g Cu added							
12	449	1254	0.491	0.508	80.43	19.54	for upper
13	525	1256	0.668	0.657	80.41	19.40	
14	556	1156	0.457	0.366	80.15	19.74	layer only
Removed melt, 145 g New charge: 325 g Cu, 275 g Cu_2S							Two liquid
15	579	1156	0.369	0.365	80.15	19.81	phases in
16	603	1208	0.437	0.426	80.27	19.63	crucible;
17	629	1253	0.512	0.492	80.50	19.63	analyses are
18	672	1308	0.593	0.563	80.17	19.75	for upper
19	693	1359	0.646	0.649	80.35	19.60	layer only
356 g melt removed 200 g Cu_2S added							
20	747	1361	0.921	0.932	80.51	19.58	
20 g Cu_2S added							
21	770	1360	1.098	1.091	80.29	19.65	
30 g Cu_2S added							
22	793	1359	2.06	2.07	79.88	20.03	
23	818	1256	2.06	2.07	79.92	20.06	
1.5 g Cu added							
24	858	1257	1.17	1.139	79.99	19.98	
100 g Cu_2S added							
25	880	1157	1.541	1.566	79.89	20.11	
26	912	1159	3.08	3.08	79.70	20.25†	
100 g Cu_2S added							
27	932	1159	11.75	11.76	79.50	20.45†	
28	939	1263	11.71	11.71	79.48	20.47†	
100 g Cu_2S added							
29	952	1362	11.57	11.65	79.44	20.51†	
30	960	1360	100.0	89.0	78.57	21.38†	
31	977	1165	100.0	87.0	78.53	21.42†	
32	985	1258	100.0		78.42	21.53†	

* For each run, zero time was at the end of several days' operation of the furnace at temperature with an H_2S-H_2 atmosphere.
† By difference from Cu analysis, allowing 0.05 pct for impurities.

system itself, apart from the melt, to equilibrium under the new conditions.

Table II summarizes the log of the experimental work. Points 1 to 9 and 20 to 32, inclusive, represent equilibria of the gas mixtures with liquid copper sulphides of varying S content up to about 21.5 pct S. For these points the ingoing gas mixtures ranged from 0.59 up to 100 pct H_2S. Except for the points at highest percentage of H_2S, the entrant and exit gases were brought to equality within 0.01 to 0.02 pct H_2S without difficulty. Points 10 to 19 represent equilibria of the gas mixtures with two conjugate melts, Cu and Cu_2S, respectively. During these ten determinations it was observed that the exit gas after once reaching the equilibrium value remained there regardless of small variations in the gas bubbled into the melt. Thus points 10, 11, and 12 represent checks of a single equilibrium condition, the exit gas remaining at 0.506 to 0.509 pct H_2S while the ingoing gas was deliberately varied from 0.527 to 0.491 pct H_2S. Points 14 and 15 show a similar check. These data illustrate the rapidity of reaction of the gas with the melt obtained by the bubbling technique. For all points except 30, 31, and 32 the percentage of H_2S in the outgoing gas is taken as the equilibrium value. The failure to reach 100 pct H_2S in the outgoing gas for points 30, 31, and 32 was associated with sulphur deposition in cold parts of the furnace tube and gas exit tubes, so for these points it was assumed that the equilibrium gas composition was that of the products of dissociation of pure H_2S at furnace temperature and pressure.

In Table III the results are placed in a more convenient form for subsequent use. The corrected values of p_{H_2S}/p_{H_2} were found as follows: First, the H_2S:H_2 ratio in the outgoing gas, as found by analysis, was corrected for dissociation of H_2S into H_2 and S_2 at the furnace temperature, using Kelley's free-energy equation for the dissociation reaction. Then preliminary plots of the data were made to estimate the rate of change of p_{H_2S}/p_{H_2} with temperature at the various compositions. These estimated temperature coefficients then were used to correct the values of p_{H_2S}/p_{H_2} from the odd measured temperatures to the even temperatures 1150°, 1250°, and 1350°C.

Table III. Equilibrium Values of $\frac{p_{H_2S}}{p_{H_2}}$ vs. Mol Fraction Sulphur at 1150°, 1250°, and 1350°C

Point No.	S, Wt Pct*	Mol Fraction S (N_S)	$\frac{p_{H_2S}}{p_{H_2}} \times 100$†
Temperature, 1150°C			
14‡	19.76	0.3281	0.353
15‡	19.82	0.3289	0.352
4	20.01	0.3316	0.677
3	20.09	0.3327	1.056
25	20.11	0.3329	1.549
26	20.26	0.3350	3.17
27	20.46	0.3378	12.82
31	21.43	0.3533	190.0
Temperature, 1250°C			
10‡			0.498
11‡	19.54	0.3250	0.501
12‡	19.54	0.3252	0.497
17‡	19.60	0.3259	0.484
9	19.65	0.3266	0.586
24	19.99	0.3313	1.166
8	20.04	0.3317	1.055
23	20.06	0.3322	2.04
2	20.12	0.3331	1.72
5	20.20	0.3342	3.01
7	20.27	0.3352	2.59
6	20.32	0.3359	2.83
28	20.48	0.3381	15.23
32	21.54	0.3528	131.0
Temperature, 1350°C			
13‡	19.42	0.3236	0.636
19‡	19.61	0.3260	0.616
20	19.56	0.3253	0.876
21	19.66	0.3267	1.032
22	20.05	0.3319	2.00
29	20.52	0.3387	12.20
30	21.39	0.3500	89.7

* Corrected pct S calculated from chemical analysis:

$$\text{Corr. Pct S} = \frac{\text{Pct S}}{\text{Pct S} + \text{Pct Cu}} \times 100$$

† Corrected for dissociation and corrected from actual experimental temperature to 1150°, 1250°, or 1350°C.

‡ Two liquid phases in equilibrium.

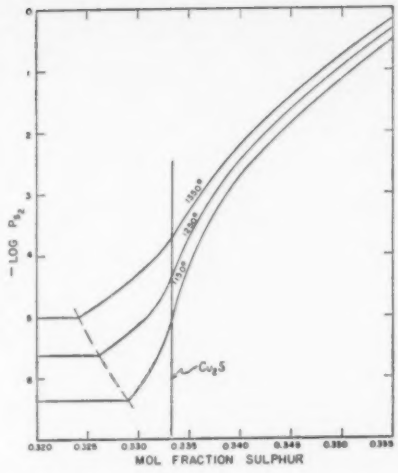


Fig. 4—Variation of sulphur pressure with mol fraction sulphur at 1150°, 1250°, and 1350°C.

Fig. 3 shows the relations of log p_{H_2S}/p_{H_2} to mol fraction S at 1150°, 1250°, and 1350°, and was plotted from the data in Table III. The horizontal lines at the left correspond to the H_2S:H_2 ratio determined with both Cu and Cu_2S phases present in the system, and these lines intersect the experimental curves at values of mol fraction S which represents the compositions of Cu-saturated sulphide melts. Several of the points plotted in Fig. 3 show rather larger deviations for the curves than might be desired. In this connection it should be noted that the scale of the abscissa is a rather expanded scale, the whole range from $N_s = 0.320$ to $N_s = 0.355$ corresponding to a range in S content of only 2.5 wt pct, from 19.2 to 21.7 pct S. This composition range is considerably smaller than was anticipated from previous work.[4] Accordingly, the scatter in Fig. 3 results chiefly from small errors in the melt analyses. In drawing the smooth curves in the vicinity of the Cu_2S composition, the following matters were considered: 1—The solid solubility of Cu in Cu_2S is small, so that the presence or absence of metallic Cu in the solid samples (determined by microscopic examination) was used as a supplementary guide in checking the analyses of samples near Cu_2S in composition.[4] 2—The curves probably should inflect at the composition Cu_2S. 3—If the curves intersect at all, all three should do so at a common point to avoid the improbable finding that the partial molal heat of solution of S in the melt varies sharply with temperature.

Fig. 4 shows the relations of p_{S_2} to composition for the three experimental temperatures. These curves were calculated to correspond to the smoothed curves of Fig. 3, using Kelley's[8] free-energy equation for the dissociation of H_2S to calculate equilibrium values of p_{S_2} corresponding to the measured values of p_{H_2S}/p_{H_2}. Kelley's data for this equilibrium are represented accurately in the temperature range of this investigation by the relation:

$$\log p_{S_2} = 2 \log \left(\frac{p_{H_2S}}{p_{H_2}} \right) - \frac{9665}{T} + 5.342$$

The plot in Fig. 4 shows the very steep variation of sulphur pressure with composition, p_{S_2} increasing from the vicinity of 10^{-6} and 10^{-5} atm for liquids below Cu_2S in sulphur content to nearly 1 atm for liquids containing a small excess of S over Cu_2S.

In view of the steep variation of sulphur pressure with sulphur content and in view of the accompanying experimental uncertainties in sulphur analyses, the data do not permit accurate determinations of the heat of solution of sulphur in the melts from the variation of sulphur activity with temperature at constant composition. However, on the basis of the smoothed data as represented by the curves in Fig. 3, the partial molal heat content of sulphur in the melt relative to H_2S gas increases from about −28,000 cal per g-atom S in Cu-saturated melts to about −12,000 cal for Cu_2S and then increases further to about +12,000 cal for the highest S melts. The corresponding estimates for the differential heat of solution of S_2 gas in the melts are −100,000 cal per g mol S_2 in Cu-saturated melts, −68,000 cal per g mol in Cu_2S, and −20,000 cal per g mol in the melts having sulphur pressures approaching an atmosphere (21.5 pct S).

Sulphur Activities and Compositions of Cu-Saturated Liquids: Fig. 5 shows the relationship of log $\frac{p_{H_2S}}{p_{H_2}}$ to $\frac{10^4}{T}$ for equilibrium determinations 10 through 19 in which two liquid phases, Cu_2S and Cu, were present at equilibrium in the crucible. The experimental points fall on a straight line within experimental error, following the relation:

$$\log \frac{H_2S}{H_2} = -\frac{2920}{T} - 0.394$$

Also plotted in Fig. 5 are the data of Cox and co-workers,[7] which check the new data reasonably well. Combination of the above equation with the relation of p_{S_2} to $\frac{p_{H_2S}}{p_{H_2}}$ and T derived from Kelley's data gives the relation of p_{S_2} to T for Cu-saturated melts:

$$\log p_{S_2} = -\frac{15,505}{T} + 4.56$$

The mol fractions of S (N_s) corresponding to Cu saturation can be read from Fig. 3 at the intersections of the horizontal lines giving log $\frac{p_{H_2S}}{p_{H_2}}$ for the systems containing two liquid phases with the curves for sulphide melts of varying composition. Table IV gives the results of these determinations and includes also the recent determination by Jensen[4] at 1105°C, which checks well with the results of the present investigation. As mentioned previously, the various determinations of the compositions of Cu-saturated mattes reported in the literature have been somewhat discordant, some of the earlier work indicating a composition range from Cu-saturation to Cu_2S as much as five times the range in percent S (e.g., 19.4 to 20.14 pct S at 1350°C) found in the present investigation. When the various experimental methods are considered, the authors feel that the data in Table IV represent the most reliable information on the compositions of Cu-saturated sulphide melts.

Activities of Cu and Cu_2S: Using the Gibbs-Duhem integration,[10] copper activities can be calculated from the relationship of sulphur activity (measured by p_{H_2S}/p_{H_2}) to mol fraction S (N_s). That is, at constant temperature:

$$\log a_{Cu} = -\int \frac{N_s}{1-N_s} \, d \log \frac{H_2S}{H_2}$$

In evaluating this integral, it is necessary to select as a limit the standard state for copper in which $a_{Cu} = 1$. It would be desirable to use pure liquid Cu as the standard state, but the data are not yet available to carry the above integration to this limit on the liquid-Cu side of the Cu-S system. Accordingly, the standard state for copper was arbitrarily chosen as the solution of composition corresponding exactly to Cu_2S, for which $N_s = 1/3$. Results of the integration based on the experimental data are plotted in Fig. 6. It can be seen that the activity of

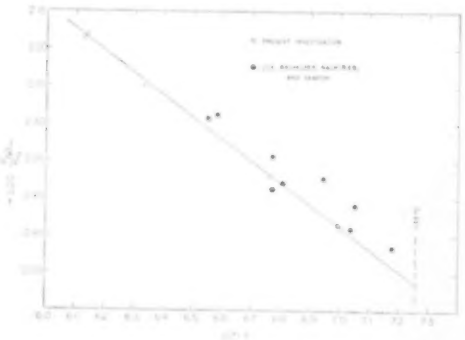


Fig. 5—Relation of log p_{H_2S}/p_{H_2} to $1/T$ for Cu-saturated melts.

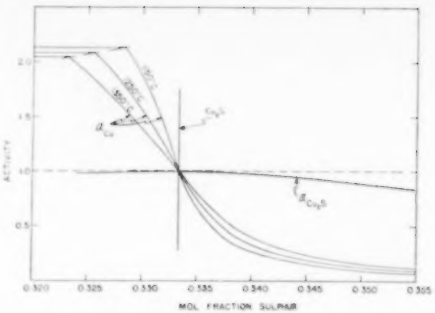


Fig. 6—Activities of Cu and Cu_2S calculated by Gibbs-Duhem integration.

Cu in liquid Cu_2S is roughly half the activity of Cu in a liquid-Cu-saturated melt, and, therefore, is a little less than half the activity of pure liquid Cu. In general, also, the activity of copper decreases rather sharply with increasing sulphur content, as would be expected from the rapid increase in sulphur pressure.

The gas-melt equilibria can be considered in terms of the reaction:

$$Cu_2S + H_2 \rightleftharpoons 2Cu + H_2S$$

for which the equilibrium constant is:

$$k = \frac{p_{H_2S}\ a_{Cu}^2}{p_{H_2}\ a_{Cu_2S}}$$

If the standard states for both Cu and Cu_2S are taken as the solution of composition Cu_2S, the equilibrium constant at any temperature becomes equal to p_{H_2S}/p_{H_2} at the composition Cu_2S and can be evaluated from the experimental data, giving:

$$\log k = -\frac{2630}{T} + 0.059$$

The corresponding equation for the standard free-energy change in the reaction is:

$$\Delta F^\circ = 12{,}000 - 0.27T$$

It should be kept in mind that this free-energy equation is valid only for the standard states of Cu and Cu_2S for which the equation is derived and thus should not be compared directly with other free-energy equations for the same reaction but based on different standard states.

Table IV. Compositions of Cu-Saturated Copper Sulphide

Temperature, °C	Mol Fraction S	S, Wt Pct	Cu_2S, Wt Pct
1350	0.323	19.4	96.3
1250	0.325	19.6	97.0
1150	0.329	19.8	98.4
1105*		19.79	

* From Jensen.[4]

Activities of Cu_2S for various compositions of liquid sulphides at various temperatures can be calculated by substituting p_{H_2S}/p_{H_2} and a_{Cu} (from the Duhem integration) into the equilibrium constant and then solving for a_{Cu_2S}. Results of these calculations are plotted in Fig. 6. One curve shows the results of the calculations adequately over the entire temperature range 1150° to 1350°C of the present investigation.

Summary

The activity of sulphur in liquid copper sulphide, from compositions corresponding to saturation with copper to compositions approaching 1 atm in sulphur pressure, was measured over the temperature range 1150° to 1350°C. The experiments consisted in finding for each melt composition and temperature the ratio p_{H_2S}/p_{H_2} in a gas mixture at equilibrium with the melt. Equilibrium was established by bubbling the gas mixture through the liquid and adjusting the gas composition until no reaction occurred, as shown by comparison of the p_{H_2S}/p_{H_2} ratio in entrant and exit gases. The equilibrium partial pressures of S_2 gas were calculated from the p_{H_2S}/p_{H_2} data, using Kelley's free-energy equation for the dissociation of H_2S.

The sulphur pressures (p_{s_2}) of liquid copper sulphides were found to be very sensitive to composition, especially as the S contents were increased beyond Cu_2S. At 1150°C, p_{s_2} was found to be 4.6×10^{-7} atm for Cu-saturated melt, 9.4×10^{-4} atm for Cu_2S (20.14 pct S), and 0.14 atm for the 21.5 pct S melt. The corresponding figures at 1250°C were 2.4×10^{-4}, 4.6×10^{-5}, and 0.23 atm, respectively, and at 1350°C were 10^{-4}, 1.8×10^{-4}, and 0.35 atm, respectively. The large increase in p_{s_2} for slight increases in S above Cu_2S accounts for the well-known fact that artificial preparations of Cu_2S involving melting in open containers always give products close to Cu_2S in composition.

The sulphur pressures (p_{s_2}) of liquid copper sulphides increase with increasing temperature, this increase being more marked for liquids below Cu_2S in sulphur content. From the variations of p_{s_2} with temperature, the partial molal heats of solution of S_2 were estimated to be approximately −100,000 cal per mol for Cu-saturated melts, −68,000 cal per mol for Cu_2S (20.14 pct S), and −20,000 cal per mol for melts with 21.5 pct S.

The equilibrium measurements for the systems containing the two conjugate solutions, liquid Cu and liquid Cu_2S, are represented by the following equation:

$$\log \frac{p_{H_2S}}{p_{H_2}} = -\frac{2920}{T} - 0.394$$

The corresponding equation for the sulphur pressure of the two-phase system is as follows:

$$\log p_{s_2} = -\frac{15{,}505}{T} + 4.56$$

The sulphur contents of the liquid copper sulphides saturated with copper were found to be 19.8 pct at 1150°C, 19.6 pct at 1250°C, and 19.4 pct at 1350°C. These results are concordant with Jensen's recent determination of 19.79 pct at 1105°C but disagree with earlier data which indicated a much larger solubility of Cu in Cu_2S.

Acknowledgments

The authors wish to express their appreciation to the International Nickel Co. for their support of this work by fellowship awards for the period 1947 to 1949. Also, the authors wish to acknowledge the assistance of L. M. Baker in making the chemical analyses.

References

[1] E. Heyn and O. Bauer: *Metallurgie* (1906) **3**, pp. 73-86.
[2] K. Friedrich and M. Waehlert: *Metall und Erz* (1913) **10**, pp. 976-979.
[3] K. Bornemann and K. Wagenmann: *Ferrum* (1913 to 1914) **11**, pp. 289-314.
[4] E. Jensen: Norske Videnskaps-Akademi, Oslo, Mat.-Naturv. Klasse, No. 6 (1947).
[5] E. Posnjak, E. T. Allen, and H. E. Merwin: *Economic Geology* (1915) **10**, pp. 491-535.
[6] K. K. Kelley: U. S. Bur. Mines *Bull.* 406 (1937).
[7] E. M. Cox, M. C. Bachelder, N. H. Nachtrieb, and A. S. Skapski: *Trans.* AIME (1949) **185**, pp. 27-31; JOURNAL OF METALS (January 1949) TP 2505C.
[8] R. Schuhmann, Jr.: *Trans.* AIME (1950) **188**, pp. 873-884; JOURNAL OF METALS (June 1950) TP 2868D.
[9] W. S. Allen and A. B. Bishop: *Journal Industrial Engineering Chemistry* (1919) **11**, p. 46.
[10] G. N. Lewis and M. Randall: *Thermodynamics.* p. 268. (1923). McGraw-Hill Book Co.

Microscopic Observation of the Solidification Of Cu-Ni Alloy Droplets

by R. E. Cech and D. Turnbull

THE supercooling behavior of pure liquid metal droplets has been described.[1] The solidification behavior of small droplets of Cu-Ni alloys as a function of composition is described herein. The Cu-Ni system is of interest for such an investigation because the components are miscible in all proportions in both the liquid and solid state and the phase diagram of the system, Fig. 1, is a type often encountered in metal systems.

It was noted by Van Riemsdyk[2] and others that the nature of the "blick" of gold droplets during assaying is not perceptibly affected by the content of the platinum group metals that are soluble in both liquid and solid gold. With the exception of these very qualitative observations there appear to have been no prior investigations of the supercooling of alloy droplets.

A series of nine alloys varying in composition by 10 pct (nominal weight) steps was made using certified OFHC copper, 99.996 pct purity, obtained from the American Brass Co., and electrolytic nickel pellets, 99.92 pct purity, obtained from the International Nickel Co. The alloys were melted and cast in vacuo in a high frequency induction furnace. Segregation was minimized by chill casting into 1-in. diam steel molds. Each alloy rod was homogenized at a temperature 50°C lower than the solidus for 100 hr in dry hydrogen. Samples for solidification experiments and chemical analysis were machined from the same portion of each rod and at a depth of ¼ in. from the rod surface. A Carboloy tool was used in taking turnings to minimize contamination of sample by the cutting tool. As a check, a number of samples for microscopic observation were chipped from the ingot with a fragment of pyrex glass. The resultant data in all cases agreed, within experimental error, with the data obtained from machined turnings.

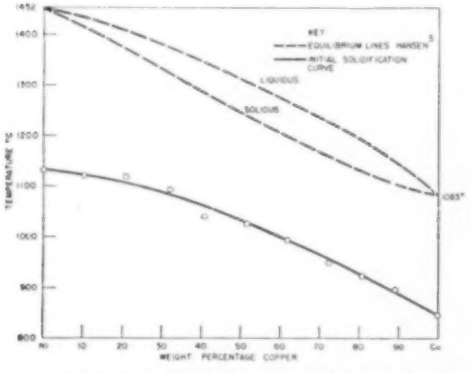


Fig. 1—Solidification temperatures of Cu-Ni alloys as a function of composition.

A number of small particles, 30 to 50 micron diam, of a Cu-Ni alloy were placed in a quartz vial 1/32 in. diam x ¼ in. long. This was inserted into a platinum ribbon heater and mounted in a high temperature microscope stage. The general procedure followed in inserting samples into the stage and measuring the temperature of melting and solidification was the same as described in an earlier paper.[1] A chromel-alumel thermocouple was used to study alloys of 88.93 pct Cu, 80.62 pct Cu, and 72.27 pct Cu. A platinum-10 pct rhodium thermocouple was used for the remainder of the alloys.

Procedure

The assembled high temperature microscope stage was first evacuated and the sample given a 2 min in situ treatment at 900°C in dry hydrogen to remove surface oxides which might otherwise catalyze crystal nucleation. After this treatment the atmosphere was changed to purified helium and melting and solidification were observed microscopically. It was not possible to determine the solidus with certainty. However, the liquidus temperature was measured very accurately since the surface of the particle changed in appearance from coarse and uneven to smooth, mirror-like within a few degrees. The visually determined liquidus temperature was checked by finding the highest temperature to which the particle could be heated such that it did not supercool upon lowering the temperature. This temperature which checked within experimental error with that found by observing surface change was assumed to be characteristic of the thermodynamic liquidus. In order to minimize the effect of selective evaporation of copper from the alloy, samples were changed frequently and the droplets were heated no more than 50°C in excess of the liquidus temperature T_l. When the latter conditions were fulfilled, T_l values were reproducible.

After melting, the temperature was decreased slowly until the particles solidified. The sudden release of heat of fusion on solidification caused the

R. E. CECH, Junior Member AIME, and D. TURNBULL, Associate Member AIME, are associated with the Research Laboratory, General Electric Co., Schenectady.

Discussion of this paper, TP 3038E, may be sent to AIME by May 1, 1951. Manuscript, Oct. 10, 1950. St. Louis Meeting, February 1951.

supercooled particles to blick, or recalesce. Also, at the same instant, the particle surface could be observed to change from mirror-like to a dendritic type pattern. It was necessary, when observing the higher melting, Ni-rich alloys to use filters to decrease radiation intensity.

Results

The alloy compositions and results are summarized in Table I and plotted on the constitution diagram of Fig. 1. The $(\Delta T_-)_{max}$ values listed for pure copper and nickel were taken from the previous investigation of pure metals.[1] The values of $(\Delta T_-)_{max}$ for the alloys are the average of several determinations on a number of samples but the maximum deviation observed in any determination was within 2 pct of the average.

In agreement with earlier observations on pure metals the frequency of supercooling to $(\Delta T_-)_{max}$ was much less in the absence of a flux. It is probable that the pyrex flux combined with nucleation catalysts that may have been picked up from the alundum crucibles used in making the alloys. When a pyrex flux was used the particles supercooled to $(\Delta T_-)_{max}$ consistently.

Occasionally, a surface oxide coating that nucleated solidification at $\Delta T_- < (\Delta T_-)_{max}$ formed on the alloys of 88.93 pct Cu and 80.62 pct Cu in a helium atmosphere. Therefore, a hydrogen atmosphere was used for these alloys. The ratio $\Delta T_{-max}/T_l$ for results obtained in hydrogen agree very well with the ratios for the other alloys of the system.

The metal droplets after solidification displayed a dendritic surface structure. A micrograph of a supercooled droplet of 80.62 pct Cu in cross-section (Fig. 2) illustrates the dendritic structure formed during solidification. It was also apparent that the solidified particle was a single crystal as might be expected in view of the rapid crystal growth rate. The dendritic segregation may indicate that at least a portion of the droplet had been heated to the equilibrium freezing temperature before solidifying. Neglecting heat losses to the surroundings, the latent heat of fusion released by the solidification of approximately 60 pct of the droplet is sufficient to heat the entire droplet to the equilibrium temperature. It is therefore apparent that segregation during solidification may occur in a supercooled alloy droplet as well as in bulk solidification.

The initial solidification temperatures are more properly defined as temperatures at which the frequency of nucleus formation becomes very great. It is known that the temperature dependence of nucleation rates in tin[4] and mercury[5] is so great that even large variations in speed of cooling will have no perceptible effect, in these experiments, on the temperature of initial solidification. To extend the knowledge of temperature dependence of nucleation rate to alloys in a qualitative way, a number of 50 micron particles of 40.89 pct Cu were first melted and then cooled to a temperature 20°C above $(\Delta T_-)_{max}$ and held 30 min. Upon further cooling they were found to solidify at $(\Delta T_-)_{max}$ thus indicating that the prolonged hold at the higher temperature had no measurable effect on the temperature of subsequent solidification.

Table I. Alloy Compositions

Alloy Composition Cu, Wt Pct*	Liquidus Temperature, °K (T_l)	Maximum Supercooling $(\Delta T_-)_{max}$,	$\frac{(\Delta T_-)_{max}}{(T_l)}$
100.00	1356 (melting point)	236	0.174
88.93	1418	254	0.179
80.62	1406	268	0.183
72.27	1511	278	0.184
61.95	1548	275	0.178
51.51	1585	281	0.177
40.89	1618	304	0.188
32.01	1633	280	0.169
20.39	1683	289	0.172
10.28	1707	314	0.184
0.00	1725 (melting point)	319	0.185

* Balance nickel.

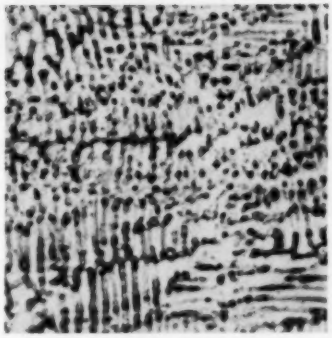


Fig. 2—Cross-section of 80.62 pct Cu alloy droplet supercooled to ΔT_{-max} before solidification. X500.

Summary

The solidification behavior of Cu-Ni alloy droplets was studied as a function of composition by means of a high temperature microscopic technique described previously.[1] The ratio of the amount of supercooling $(\Delta T_-)_{max}$ to the absolute liquidus temperature was found to be 0.18 ± 0.01, see Table I, which checks closely the value of 0.18 ± 0.02 for the ratio of $(\Delta T_-)_{max}$ to the absolute melting temperature found for pure metals.

A cross-section of a supercooled particle displayed segregation indicating that the heat of fusion was probably sufficient to raise the droplet to the equilibrium freezing temperature and allow a portion of the particle to solidify by normal dendritic growth.

It was demonstrated that the temperature dependence of the nucleation rate was about as large as for pure metals.

Acknowledgment

The authors are pleased to acknowledge the assistance of Mrs. Joyce Rowland in much of the experimental work reported in this paper.

References

[1] D. Turnbull and R. E. Cech: Microscopic Observation of the Solidification of Small Metal Droplets. *Journal of Applied Physics* (1950) **21**, p. 804.

[2] A. D. Van Riemsdyk: Eclair des Essais D'Or. *Annales de Chimie et de Physique* (1880) **20**, p. 66.

[3] M. Hansen: *Der Aufbau der Zweistofflegierungen.* (1936) Berlin. Springer.

[4] B. Vonnegut: Variation with Temperature of the Nucleation Rate of Supercooled Tin and Water Drops. *Journal of Colloid Science* (1948) **3**, p. 563.

[5] D. Turnbull: Isothermal Rate of Solidification of Small Droplets of Mercury and Tin. *Journal Chem. Phys.* (1950) **18**, p. 768.

Solubility of Hydrogen in Molten Lead

by W. R. Opie and N. J. Grant

THE amount of hydrogen that will dissolve in lead has been considered negligible. However, a limited number of measurements made recently using apparatus built for determining hydrogen solubility in aluminum alloys[1] indicate that liquid lead will hold a small but appreciable amount of hydrogen in solution. The apparatus used was similar to that developed by Sieverts.[2] This consists of a bulb to hold the molten metal, a gas burette for introducing a measured quantity of gas into the bulb and a manometer for measuring the gas pressure in the bulb. Measurements are made by introducing enough of an insoluble gas (helium) to fill the system at a given temperature and pressure, thereby determining the hot volume of the bulb. This gas then is pumped out and hydrogen is introduced until the same pressure is reached, the metal being maintained at the same temperature while in contact with each gas. The difference between the volumes corrected for pressure is then the hydrogen solubility. A more detailed account of the procedure can be found in refs. 1 and 2.

The lead was melted in an alundum crucible by induction heating to provide uniform temperature and an important stirring effect. The metal was the purest obtainable, 99.999+, prepared especially by the research department of the American Smelting and Refining Co. Measurements were made by approaching the equilibrium value from high and low temperatures during the constant pressure runs, and from high and low pressures when the temperature was held constant. Thus a number of measurements were made on each of two large samples which weighed 336 and 398 g. The gases were purified as described in ref. 1.

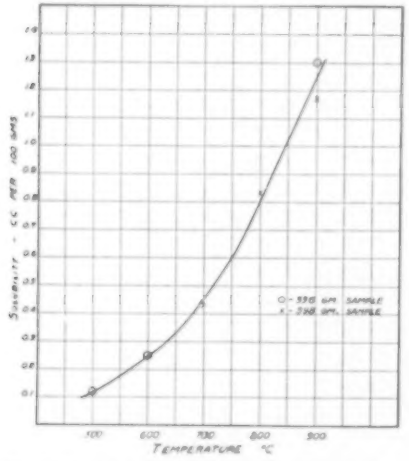


Fig. 1—Effect of temperature upon the solubility of hydrogen in molten lead at 760 mm Hg.

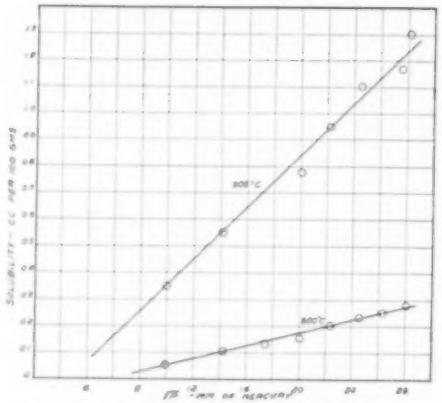


Fig. 2—Effect of pressure upon the solubility of hydrogen in molten lead.

The effect of temperature on the solubility was studied with the pressure held constant at 760 mm of Hg. To show the effect of pressure, solubility measurements were taken at two constant temperatures, 600° and 900°C.

Results

The effect of temperature on hydrogen solubility is shown in Fig. 1. The curve representing the data is parabolic, as are plots of hydrogen solubility vs. temperature for other metals and alloys (aluminum,[1] copper,[2] and iron,[4] for example). Fig. 2 shows the relationship that exists when the solubility is

W. R. OPIE, Junior Member AIME, is Research Metallurgist, Titanium Div., National Lead Co., Fords, N. J.; and N. J. GRANT, Member AIME, is Associate Professor, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge.

Discussion of this paper, TP 3037E, may be sent to AIME by May 1, 1951. Manuscript, Oct. 2, 1950. St. Louis Meeting, February 1951.

plotted against the square root of the pressure. As can be seen from this plot, the Sieverts' relationship, "solubility of a diatomic gas varies as the square root of the pressure if the temperature remains constant," can be applied to lead. The fact that the lines relating the solubility to the square root of the pressure do not quite pass through the origin indicates that the values are slightly low. This can be explained primarily by the difference in heat conductivity between hydrogen and helium but also by the small values of solubility being measured. Hydrogen, being a better conductor than helium, would heat the surrounding bulb glassware above the metal to a slightly higher temperature than would the helium. Because the space in the system occupied by the gas is hotter when hydrogen is in contact with the metal, the net result is that less hydrogen than helium for a given pressure is needed to fill this space. This effect is very much more pronounced when a gas with even lower heat conductivity, such as argon, is used as the inert gas, as was observed in several trial runs.

When the equilibrium constant $\log_{10}$ for the solubility equation:

$$2Pb + H_2 \rightleftharpoons 2PbH$$

determined by expressing the solubility as the mol fraction, is plotted against the reciprocal of the absolute temperature, the heat of solution can be calculated from the slope of the line using the Van't Hoff equation:

$$\text{Log}_{10} K = \frac{-\Delta H}{0.575\,T} + C$$

Fig. 3 is such a plot with the solubility, ($\log_{10}$) expressed in cc of hydrogen per 100 g of lead, and the equilibrium constant ($\log_{10}$) both plotted against the reciprocal absolute temperature. From this plot the solubility may be expressed as:

$$\log_{10} S = \frac{-2450}{T} + 2.19$$

The total heat of solution, including the heat of dissociation of diatomic to monatomic hydrogen and the heat of solution of the monatomic hydrogen, has been determined from the slope to be 22,300 cal per mol of diatomic hydrogen.

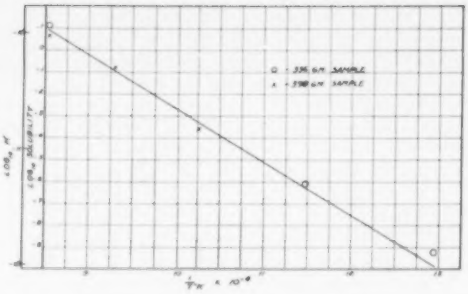


Fig. 3—Van't Hoff plot of solubility data.

Conclusions

1—The solubility of hydrogen in molten lead may be expressed by the equation:

$$\log_{10} S = \frac{-2450}{T} + 2.19$$

2—Sieverts' law is obeyed within the temperature and pressure ranges investigated.

3—The heat of solution of hydrogen in lead is 22,300 cal per mol of diatomic hydrogen.

Acknowledgment

The authors wish to thank Edith Weiser for her assistance in obtaining the results. The work was sponsored by the Bureau of Aeronautics.

References

[1] W. R. Opie and N. J. Grant: *Trans.* AIME (1950) **188**, p. 1237; JOURNAL OF METALS (October 1950) TP 2928E.

[2] A. Sieverts: *Ztsch. Metallkunde* (1929) **21**, p. 37.

[3] M. B. Bever and C. F. Floe: *Trans.* AIME (1944) **156**, p. 149; METALS TECHNOLOGY (April 1944) TP 1703E.

[4] H. Liang, M. B. Bever, and C. F. Floe: *Trans.* AIME (1946) **167**, p. 395; METALS TECHNOLOGY (February 1946) TP 1975C.

Technical Note

Surface Diffusion in Sintering of Spheres on Planes

by P. Schwed

IN determining the mechanism responsible for sintering, the most direct procedure available is the comparison of the observed time and temperature dependence of the process with the dependence to be expected upon the basis of each conceivable mechanism. This was done by Kuczynski[1] who, in treating the mechanism of surface diffusion, postulated, in effect, that the concentration gradient of vacancies is different from zero only within the neck. This procedure was recently questioned by Cabrera[2] who assumed, on the contrary, that diffusion occurs only in the region outside the neck. In the present note, the calculations are performed without restriction on the region of diffusion.

To carry out this objective it is first necessary to

P. SCHWED is associated with National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, Cleveland.

TN 68E. Manuscript, Dec. 14, 1950.

review briefly Cabrera's approach. He divided the surface of the sphere being sintered into two parts: 1—A flat portion, AB in Fig. 1, with an essentially infinite radius of curvature; and 2—the neck, AA in Fig. 1, which at a given stage of the process has a radius of curvature, ρ. This difference in curvature leads to a higher concentration of vacancies in the neck with the result that diffusion of atoms occurs into the neck from the undisturbed part of the surface. It is assumed further that there exists a process, say condensation, which replaces the atoms lost from the flat part of the surface; and the equation of continuity is solved for this region of the surface under the assumption that diffusion and condensation balance (time independence) and with the boundary condition that the concentration of atoms at the junction, A, between the neck and the flat surface is that appropriate to the neck. The current at the junction then is calculated, and from the current the law of growth of the neck may be found.

This approach suffers from the difficulty that the equation of continuity does not hold throughout the surface, since the current of atoms is discontinuous across the boundary. This follows from the fact that the concentration of atoms in the neck is taken as constant so that the current of atoms within the neck is everywhere zero, according to the diffusion equation. The inconsistency here arises from a failure to consider in proper detail the situation at the surface of the neck. The most direct way of doing this is to apply the same principles to calculating the concentration in the neck as were employed for the flat surface. This means that the process which supplies the atoms lost by the flat region removes the excess atoms in the neck, for instance by evaporation.

Revising Cabrera's notation slightly, let n_i be the concentration of adsorbed atoms in the flat region and n_n that in the neck; further, let y be a coordinate measured from the junction A with a positive direction away from the neck and $y_c = (D_s t_c)^{1/2}$ where D_s is the coefficient of surface diffusion and t_c is the relaxation time for condensation. Then, if $n(\infty)$ and $n(\rho)$ are the equilibrium concentrations of adsorbed atoms in the flat surface and neck, respectively, the appropriate equations are (cf. ref. 2, eq 3):

$$\frac{d^2}{dy^2}\,[n(\infty) - n_i] = \frac{n(\infty) - n_i}{y_c^2} \qquad [1]$$

and

$$\frac{d^2}{dy^2}\,[n(\rho) - n_i] = \frac{n(\rho) - n_i}{y_c^2} \qquad [2]$$

Eq 2 is based upon the assumption that diffusion occurs along the curved surface of the neck in essentially the same fashion as on a plane surface of the same length. The following boundary conditions apply:

$$\begin{aligned} n_i &= 0 \text{ at } y = \infty \\ n_i &= n_n \text{ at } y = 0 \\ \frac{dn_i}{dy} &= \frac{dn_n}{dy} \text{ at } y = 0 \qquad [3] \\ \frac{dn_i}{dy} &= 0 \text{ at } y = y_c = -\frac{\pi\rho}{2} \text{ (center of neck)} \end{aligned}$$

where y_c is the coordinate of the center of the neck.

The last two follow respectively from the equality of currents at the junction A and the vanishing of the current at the center C, of the neck on account

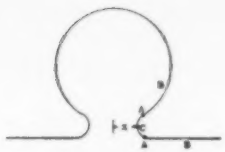


Fig. 1—Typical sphere.

of symmetry. The solution of eqs 1 and 2 subject to the conditions of eq 3 is:

$$n(\infty) - n_i = \frac{n(\infty) - n(\rho)}{2}\left(1 - e^{-\frac{\pi y_c}{y_c}}\right) e^{-\frac{y}{y_c}}$$

$$n(\rho) - n_i = -\left[\frac{n(\infty) - n(\rho)}{2}\right]\left(e^{-\frac{y}{y_c}} + e^{-\frac{-\pi + \pi y_c}{y_c}}\right) \qquad [4]$$

The current J_s through the junction A is therefore:

$$J_s = \frac{n(\infty) - n(\rho)}{2}\,\frac{D_s}{y_c}\left(1 - e^{-\frac{\pi y_c}{y_c}}\right)$$

$$= \frac{n(\infty) - n(\rho)}{2}\,\frac{D_s}{y_c}\left(1 - e^{-\frac{\pi\rho}{y_c}}\right) \qquad [5]$$

In interpreting eq 5, it is necessary to exercise caution. If the process balancing diffusion is literally condensation or evaporation, the current found leads to no net growth since the atoms entering the neck are evaporated forthwith. If, however, the alternative suggestion of Cabrera's is followed, that the interchanges implied are between atoms in the kinks on the surface and normal surface atoms, the observed build-up of the surface of the neck occurs since the atoms entering the neck remain there. Assuming the latter process to be correct, eq 5 may be used to find the rate of sintering. For $\rho << \frac{y_c}{\pi}$, $1 - e^{-\frac{\pi\rho}{y_c}}$ is nearly equal to $\frac{\pi\rho}{y_c}$, and, because $n(\infty) - n(\rho)$ varies as $\frac{1}{\rho}$, J_s, as given by eq 5, is independent of ρ and the law of growth of the neck is $x^5 \sim At$ where $2x$ is the neck diameter. On the other hand, for $\rho >> \frac{y_c}{\pi}$, the law of growth is $x^3 \sim At$ and is the same as for volume diffusion. It follows that on the present theory it is possible to distinguish surface diffusion from volume diffusion by experiments on small particles.

To expedite comparison of the three calculations a brief table giving the results of each of these is as follows:

	$\rho << \frac{y_c}{\pi}$	$\rho >> \frac{y_c}{\pi}$
Kuczynski[1]	$x^7 \sim At$	$x^3 \sim At$
Cabrera[2]	$x^5 \sim At$	$x^3 \sim At$
Eq 5	$x^5 \sim At$	$x^3 \sim At$

References

[1] G. C. Kuczynski: *Trans.* AIME (1949) **185**, p. 169; JOURNAL OF METALS (February 1949) TP 2528E.

[2] N. Cabrera: *Trans.* AIME (1950) **188**, p. 667; JOURNAL OF METALS (April 1950) TN 35E.

Technical Note

Re-solution of Precipitated Silver in Copper-Silver Alloys

by Harold Margolin and Walter R. Hibbard, Jr

DURING preliminary tests on the aging of a Cu-plus 5 pct Ag alloy,[1] a specimen which had been overaged 24 hr at 550°C was annealed in a nitrogen-hydrogen atmosphere first for 2 hr and then for an additional 28 hr at 600°C. After each anneal the specimen was cooled to room temperature in about ½ hr and X-ray photograms were made. The first film, Fig. 1a, revealed two sets of copper-base lines, one intense and corresponding to the parameter at 550°C, the other fainter and shifted away from the beam, corresponding to the larger parameter at 600°C (see arrows). The 30-hr film, Fig. 1b, revealed the same two sets of copper-base lines with a reversal of intensity. In neither case do the copper lines form a broad band which would be indicative of a range of compositions. This phenomenon is thus a "discontinuous" type of solution. A similar phenomenon was observed in a Ag-rich Cu-Ag alloy.[2] Finlay and Hibbard[3] have suggested that directional rather than random solution of precipitate occurs in some alloys.

Conceivably, for Cu-Ag alloys, the matrix-transition-precipitate precipitation sequence is reversible for the re-solution of the precipitate caused by rapidly raising the annealing temperature of an overaged specimen. A copper-base transition structure supersaturated with solute might be formed around the precipitate as it dissolves, thus obviating the necessity for a gradually changing solute composition of the matrix. The solute atoms then might be transferred rapidly and locally from the transition to the matrix phase in the proper amount and at the proper location to obtain directly the new expanded solid solution. The theory implies a minimum of diffusion of solute in the matrix (i.e., no significant range of matrix composition) and possibly suggests that the composition of the transition structure will vary with the conditions of re-solution. A transition copper phase found in aged Cu-Ag alloys[1] might fulfill this function.

Fig. 1a (top)—Cu-Ag alloy aged 24 hr at 550°C, annealed 2 hr at 600°C.

Fig. 1b (bottom)—Same as Fig. 1a, but annealed 30 hr at 600°C.

Evidence regarding this suggestion could be obtained in Cu-Ag alloys by overaging a specimen until no trace of the expanded copper lattice is present and then subjecting the specimen to a retrogression treatment. Re-appearance of the transition copper phase would confirm the theory. Additional details could be secured by varying both aging and retrogression temperatures.

HAROLD MARGOLIN is Research Associate, Research Div., New York University, New York, and WALTER R. HIBBARD, JR., Member AIME, is Associate Professor of Metallurgy, Yale University, New Haven, Conn.

TN 70E. Manuscript, Dec. 8, 1950.

This note is part of a dissertation by Harold Margolin submitted in partial fulfillment of requirements for degree of Doctor of Engineering to Faculty of the School of Engineering, Yale University.

References

[1] H. Margolin and W. R. Hibbard, Jr.: Effect of Ternary Additions on the Age Hardening of a Copper-Silver Alloy. *Trans.* AIME (1951) **191**, p. 174; JOURNAL OF METALS (Feb. 1951) TP 3002E.

[2] N. Ageew, M. Hansen, and G. Sachs: Decomposition and Changes in Properties of Super-saturated Silver-Copper Alloys. *Ztsch. Physik* (1930) **66**, p. 350.

[3] W. L. Finlay and W. R. Hibbard, Jr.: Some Effects of Applied Stresses on Precipitation Phenomena. *Trans.* AIME (1949) **180**, p. 255; METALS TECHNOLOGY (Sept. 1948) TP 2470E.

Technical Note

Fractographic Pattern for 475°C Embrittlement in Stainless Steel

by Carl A. Zapffe

FOR a number of years a puzzling phenomenon of brittleness in Class II ferritic stainless steels, developing in the temperature range near 475°C, has received increasing attention, but its nature remains essentially unknown. During an investigation of the fractographic structures in stainless steels, conducted in the author's laboratory the past several years, principally under sponsorship of the Office of Naval Research, some observations of a new kind were found for "475°C embrittlement."

While the details of the study cannot be given here,[1] three fractographs will suffice to carry the

CARL A. ZAPFFE, Member AIME, is Consulting Metallurgist, Baltimore.

TN 54E. Manuscript, Nov. 24, 1950.

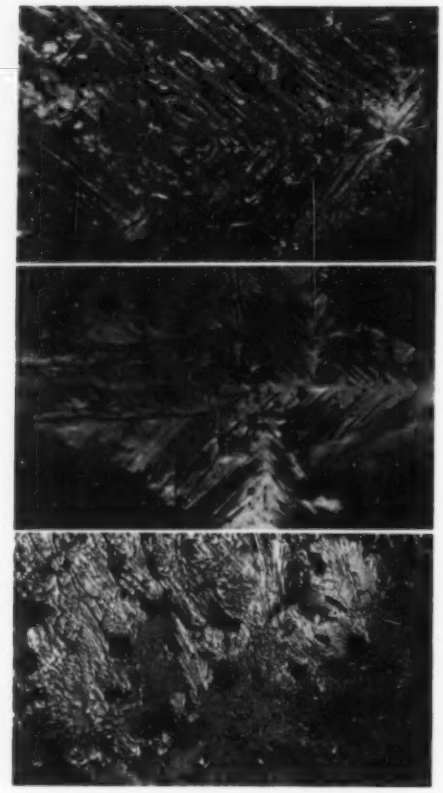


Fig. 1a (top)—Fractographic pattern for Type 446 stainless steel produced by rifle fire at 100°C, showing transgranular fracture typical for both embrittled and unembrittled metal at temperatures below the fractological change.

Fig. 1b (center)—Specimen fractured by rifle fire at 475°C. Still transgranular, the pattern expresses the fractological change, the crystallographic markings now representing slip rather than intersecting cleavages.

Fig. 1c (bottom)—Fractographic pattern believed to reveal a grain boundary precipitate and the phenomenon responsible for 475° embrittlement.

Figs. 1a-1c: X850. Area reduced approximately 25 pct for reproduction.

point. These concern a sample of Type 446 stainless steel, held at 1150°C for 2½ hr, and slowly cooled in the furnace both to grow large grains and to expose the material to 475°C embrittlement as it passed through that range. Numerous other tests were conducted also, including some in which the specimens were held for 200 hr at temperatures within the embrittling range, but the results of all tests were similar.

In Fig. 1a a fractograph is shown for this steel fractured at 100°C by rifle fire from a 0.22-caliber bullet at a distance of 24 in. from the muzzle. The specimen was ¼-in. round bar containing a rectangular notch. The pattern discloses a sharp rectangular symmetry of transgranular cleavage traverse on (001). Intersecting {100} cleavages are clearly evident. All visible angular relationships lie primarily at 90°, also at 45°.

This pattern is typical for *transgranular fracture* through this grade of steel whether fractured by hammer blow or by rifle fire over a wide range of temperature, and whether the metal has been embrittled or not by the phenomenon under discussion. No observable change in transgranular fracture pattern was caused by 475° embrittlement.

At temperatures above approximately 100°C, a fractological change manifests itself for specimens broken by hammer blow,[2] clastic responses being preceded by important plastic deformation with consequent obscuration of the fractographic pattern. By means of the higher velocity of rifle fire, the temperature of this fractological change is shifted upwards, such that a certain proportion of observable transgranular facets persists even at 475°C. One of these is shown in Fig. 1b. It will be noted that the pattern remains relatively flat, but that few if any of the block-like markings are in evidence. The parallel traces in this figure are believed to be slip markings, probably on {110}.

Although fracture in embrittled steel is predominantly transgranular, as just shown, an occasional facet is found such as that in Fig. 1c. There the completely altered texture resembles nothing so far found in specimens free from embrittlement. The study of a number of these patterns is convincing that they represent surfaces of individual grains, and that a superficial phase forming along the grain boundaries is directly associated with 475° embrittlement. While at first it seems strange that a grain boundary phase should promote transgranular clasticity, exactly that relationship generally has been agreed upon by previous investigators.

No steps have been taken for direct analysis of this superficial coating; but its general appearance carries a strong similarity with an intergranular coating in cast molybdenum known to be molybdenum oxide.[3] A possibility then presents itself to hypothecate that the phenomenon of 475° embrittlement involves a *chromium oxide*, rather than an intermetallic combination of Fe and Cr.

Further, it is proposed that some attention be paid the protoxide CrO as a possible factor. Chromium monoxide has been identified in several research fields as a prominent constituent of chromiferous steels,[4] and one which deserves further attention by metallurgists. The protoxide is particularly significant because it represents the oxide phase having a direct relationship with oxygen dissolved in the metal—such as FeO in the Fe-O system. Thus it can precipitate and redissolve in crossing its saturation boundary, much in conformity with known effects of thermal treatments on 475° embrittlement.

References

[1] C. A. Zapffe and C. O. Worden: Observations on 475° Embrittlement in Stainless Steel. Unpublished.

[2] C. A. Zapffe and C. O. Worden: Temperature and Velocity of Fracture as Factors Affecting Fractographic Patterns of Steel. Unpublished.

[3] C. A. Zapffe, F. K. Landgraf, and C. O. Worden: Fractographic Study of Cast Molybdenum. *Trans.* AIME (1949) **180**, pp. 616-636; METALS TECHNOLOGY (Aug. 1948) TP 2421E.

[4] C. A. Zapffe: Dissociation Reactions Within Inclusions. *Journal* Iron and Steel Inst. (1946) **154**, No. 2, pp. 155-160; discussion, pp. 160-161.

Technical Note

Structure of Spherulites in Nodular Cast Iron

by H. E. Stauss, F. W. Von Batchelder, and E. I. Salkovitz

EXISTING information regarding the structure of a spherulite in nodular cast iron is based on optical studies. According to these data, a nodule consists of an aggregate of graphite crystallites radiating from the center, with the closely packed basal planes at right angles to the radii. The c axes lie along the radii. This view faces some uncertainty in the fact that the c axis does not represent the accepted direction of fastest growth in graphite.

To supplement the optical information, X-ray studies have now been made. The principle used was to screen the nodule in greater part from the X-ray beam and expose only a minor cap. As successively larger portions of the nodule were introduced into the X-ray beam, any differences in the X-ray patterns could be observed. Such photographs have been taken with chromium radiation and a Laue camera. The graphite nodule itself, about 0.010 to 0.025 in. in diam, was mounted with vaseline on a micrometer screw for control of the linear motion. The nodule rotated about 45° each time that it was translated linearly. The nodules were obtained from magnesium-treated hypereutectic iron by electrolytic solution of the iron in hydrochloric acid.

In Fig. 1a is shown the pattern of the thinnest cap examined. In Fig. 1b is shown the pattern of the same nodule moved 0.003 in. farther into the X-ray beam, and rotated 45° at the same time. Figs. 1a and 1b indicate incomplete circles for graphite (the two outer circles arise from graphite) with the side arcs much weaker than the top and bottom ones. The arcs obtained are themselves not continuous in intensity but vary with maxima of intensity some 15° and 30° apart.

The structure of the nodule that would give rise to such a pattern can be explained as follows. Basically the nodule consisted of small crystallites. The discontinuous character of the diffraction rings demonstrates that the nodule was not composed of randomly oriented crystallites. The strong vertical reflections and the weak lateral reflections show that the reflecting planes were roughly normal to the radii. The absence of sharp reflection spots suggests that the nodule did not contain large crystals. The sharpness of the diffraction rings in their radial direction shows that the variations in intensity along the arcs were not the result of line broadening resulting from extremely small crystals. In the diffraction patterns two rings corresponding to graphite were found. The third and inner ring in the figures originated in the vaseline. The graphite rings correspond to the α and β lines reflected from the basal planes, showing that the radii of the nodules are the [0001] direction normal to the basal planes of graphite.

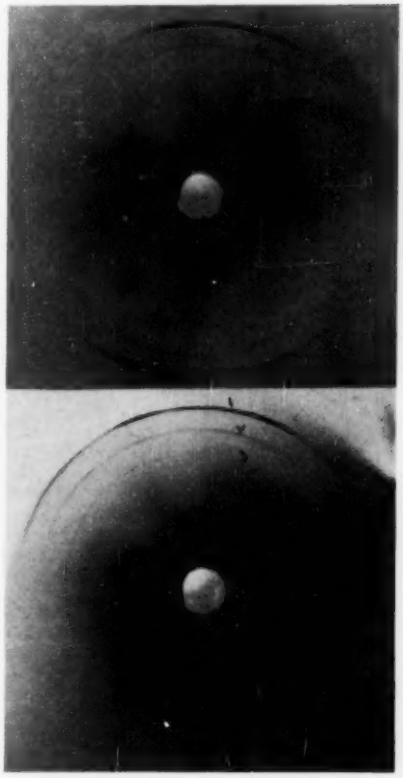


Fig. 1a (top)—Laue pattern of thinnest cap of graphite spherulite from magnesium inoculated hypereutectic iron.

Fig. 1b (bottom)—Laue pattern of spherulite moved 0.003 in. farther into X-ray beam.

The picture of the structure that is formed is, therefore, one of aggregates of crystallites. Within each aggregate the c axes of the crystallites tend to align themselves in the radial direction of the nodule, although these axes deviate somewhat in direction by a continuous variation of angle. Correspondingly the basal planes of the graphite crystallites are generally normal to the radii.

It is a pleasure to acknowledge the assistance of M. C. Bloom and R. P. Dunphy of this laboratory.

H. E. STAUSS, Member AIME, F. W. VON BATCHELDER, and E. I. SALKOVITZ are associated with the Metallurgy Division, Naval Research Laboratory, Washington.

TN 67E. Manuscript, Dec. 5, 1950.

Technical Note

Deformation and Recrystallization Texture Of Cold-Drawn OFHC Copper Wire

by W. A. Backofen

THE texture of cold-drawn copper wire has been described most often as a composite of [111] and [100] directions aligned parallel to the wire axis.[1] Hibbard[2] suggested that sufficient reduction will result in a single [111] texture and reported that after a reduction in area of 96.4 pct, such a texture was nearly obtained. Other work[3, 4] has shown that recrystallization within the temperature range of 300° to 1000°C does not alter the texture established by cold-drawing. In general, however, the texture of cold-drawn and annealed copper wire is not as well defined as the deformation texture. In the work reported here it was found that the double-fiber, deformation texture persists even after a reduction in area of 97.3 pct, and after recrystallization the texture is practically all [100].

The wire used in this work was prepared in the following way. A ¾-in. diam length of annealed OFHC copper was cold-drawn to a diameter of ⅛ in., a reduction in area of 97.3 pct. Each step in the drawing operation brought about a reduction in area that varied from 6 to 10 pct. Short lengths of this wire were etched in a 50-pct solution of nitric acid to a diameter of approximately 0.01 in.

The texture of the cold-drawn specimens was determined with the conventional X-ray transmission diffraction technique using filtered copper radiation. The X-ray beam was directed perpendicularly to the wire axis and the diffraction rings were recorded on a flat film. Fig. 1a is typical of the photograms obtained and reveals that the cold-drawing schedule described above introduces a distinct, double-fiber texture with both [111] and [100] directions aligned parallel to the wire axis. Supplementary measurements with a Geiger-Mueller counter of the intensity of reflection from (111) planes showed that the [111] component was much more predominant than the [100].

Additional specimens of the drawn and etched wire were annealed in a salt bath at temperatures from 300° to 450°C. The texture of the recrystallized wire was studied with the same technique applied to the cold-drawn wire. Fig. 1b is an X-ray photogram of a specimen annealed for 1½ hr at 300°C and is typical of those obtained from recrystallized specimens. The photogram shows that recrystallization of this material is accompanied by the almost complete elimination of the [111] component of the deformation texture. A pronounced strengthening of the [100] component was evident from intensity measurements with a Geiger-Mueller counter.

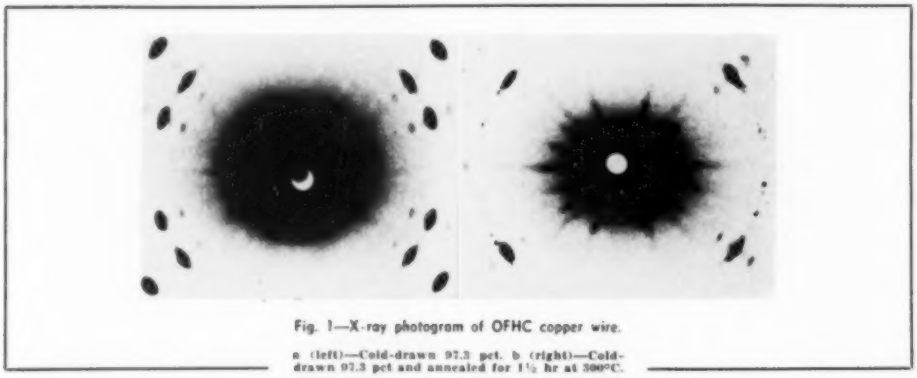


Fig. 1—X-ray photogram of OFHC copper wire.

a (left)—Cold-drawn 97.3 pct. b (right)—Cold-drawn 97.3 pct and annealed for 1½ hr at 300°C.

The wire axis is in the vertical position. The inner diffraction ring is from (111) planes. The outer diffraction ring is from (200) planes.

In summary, the deformation texture of cold-drawn OFHC copper wire, after a reduction in area of 97.3 pct, may still be described as a composite of [111] and [100] directions aligned parallel to the wire axis. Recrystallization of such wire at temperatures from 300° to 450°C introduces a texture which consists almost entirely of a [100] alignment.

Acknowledgment

Sidney Rolle of the Scomet Engineering Co. generously supplied the OFHC copper used in this work.

References

[1] C. S. Barrett: *Structure of Metals*. p. 382 (1943) New York. McGraw-Hill Book Co.

[2] W. R. Hibbard, Jr.: *Trans.* AIME (1949) **185**, p. 598; JOURNAL OF METALS (Sept. 1949) TN 19E.

[3] P. 422 of ref. 1.

[4] E. Schmid and G. Wasserman: *Ztsch. Physik* (1926) **40**, p. 451.

W. A. BACKOFEN, Student Associate AIME, is Assistant Professor of Metallurgy, Massachusetts Institute of Technology, Cambridge.

TN 53E. Manuscript, Dec. 4, 1950.

Intergranular Energy of Iron and Some Iron Alloys

by Lawrence H. Van Vlack

The energy of the γ-iron grain boundary was determined to be 850 ergs per cm^2 at 1105°C. The α/α and the α/γ boundaries possess somewhat less energy. The microstructures of several iron alloys are discussed in terms of the interfacial energy relationships.

THE dependence of the shape of liquid interfaces upon their energies has been studied for some time.[1-3] Recently, Smith[4] concluded that many of the microstructures observed in metals may be attributed to the energies of the interfaces between the grains and phases.

While the energies of liquid surfaces have been measured by numerous different methods,[5] only two attempts have been made to determine experimentally the energy of surfaces involving crystalline solids. Udin, Shaler, and Wulff[6] used a procedure introduced by Berggren[7] to measure the surface tension of solid copper. It consisted of determining the load required on a thin copper wire so that the surface tension was counteracted, and no net strain resulted. Bailey and Watkins[8] used a different technique and were able to determine both the surface tension of copper and the tension of the copper grain boundary. They measured the contact angle which liquid lead makes against a copper surface. They then calculated the above energies from the surface energy of liquid lead by using the Pb vs. Cu/Cu* dihedral angle and the surface groove angle formed during thermal etching. They obtained a value of 1800 dynes per cm for the surface tension of clean copper and approximately 640 dynes per cm for the tension of copper grain boundaries. The former value was somewhat higher than Udin's value of 1500 dynes per cm.

This paper includes a determination of the energy of the γ-iron grain boundary. In addition, the microstructural relationships of several other metallic and nonmetallic phases with iron were examined and an attempt was made to interpret the observed structures in terms of interfacial energy relationships.

Theoretical Considerations

In a three-phase material containing a solid and two liquids, there may be two solid/liquid interfaces, one liquid/liquid interface and one intergranular interface. Liquid/liquid interfacial energies can be measured directly. Therefore, by determining the energy of such an interface and by measuring the required interfacial angles,[9] the energies of the interfaces involving solids may be obtained.[10] They may be shown schematically as in Fig. 1.

The above procedure requires the following assumptions: 1—The interfacial energies are, in general, unaffected by boundary orientation, and 2—the shapes of the interfaces are unaltered between annealing and sectioning for microscopic examination. The first assumption is good to a first approximation as shown by Dunn and Lionetti[11] except for a few critically orientated boundaries. Two conditions may alter the shape of a boundary upon cooling: 1—Precipitation of dissolved material upon one side of the interface, and 2—a change in volume during the transition from one phase modification to another. The former must be detected by microscopic observation. The latter may become appreciable in systems containing an interface between two liquids which solidify after annealing. However, possible movement of the two-liquid interface may be checked in the system diagrammed in Fig. 1 by measuring θ, for example, and comparing it with its value as calculated from the other interfacial angles by:

$$\tan \theta_z = \frac{-\sin \theta_z}{\dfrac{\cos \dfrac{\theta_z}{2}}{\cos \dfrac{\theta_x}{2}} + \cos \theta_z} \qquad [1]$$

The choice of a suitable pair of liquids is limited by several factors. The relative values of the several

* This notation, first employed by Smith[4] and followed by others, indicates the angle formed by one phase between the two adjacent grains (or phases).

LAWRENCE H. VAN VLACK is associated with the U. S. Steel Co., South Works, Chicago.

Discussion of this paper, TP 3029E, may be sent (2 copies) to AIME by May 1, 1951. Manuscript, Oct. 9, 1950; revision, Jan. 12, 1951. St. Louis Meeting, February 1951.

This paper represents part of a thesis by the author submitted in partial fulfillment of requirements of the degree of Doctor of Philosophy to the University of Chicago.

interfacial energies should be such that the interfacial angles—θ_1, θ_2, and θ_3—are as small as possible but still are greater than zero. The interface should be mobile enough so that it adjusts to the equilibrium shape in a reasonably short length of time. In addition, neither liquid should react with the solid to give a fourth phase.

Few liquid pairs contain all the above features. The two liquids, "copper" and "copper sulphide," most nearly met the requirements for use with iron. As such, they were not pure liquids, as shown in Fig. 2. Likewise, the iron surface became saturated with copper and sulphur.

The interfacial energy, γ, between liquid "copper" and liquid "copper sulphide" was measured by the differential capillary depression of their interface in two fused-silica tubes of unequal radii, as diagrammed in Fig. 3, in which:

$$\gamma = \frac{\Delta H\, g\, (D-d)}{2\cos\phi} \quad \frac{(\ b_1 b_2\ )}{b_2 - b_1} \qquad [2]$$

The contact angle, ϕ, with these phases was 180° (or 0° as the case may be). The difference in meniscus levels, ΔH, was determined radiographically; D and d are the densities of the two liquids; g is 980.6 cm per sec²; and b_1 and b_2 were the radii of curvatures for the centers of the two menisci.

The radii of curvatures were not identical with the tube radii because the capillaries and the density differentials were too large for the menisci to approximate a hemisphere. However, the shape of a meniscus surface with a contact angle of 180° is the same as the surface of a drop with a contact angle of 90°, as shown in Fig. 4. Therefore, the radii of surface curvature may be calculated from the tube radii and the approximate capillary constant by following Sugden's[10] treatment of Bashforth and Adams' tables.

Experimental Technique

The procedure chosen for the determination of the intergranular energy of iron required two separate experiments: 1—A determination of the relative energies of the several interfaces in an iron-copper-copper sulphide alloy, and 2—a determination of the energy of the liquid copper/liquid copper sulphide interface.

The former was obtained from the dihedral angles in a sample containing the three phases. The angles were measured with a protractor on a rotating micrometer ocular at a magnification of about X600. At least 100, and as many as 200, angles were measured between each of the required interfaces. Following Harker and Parker's work[9] the most frequently observed angles were considered to be within ±5° of the true interfacial angle.

The samples for microscopic examination were made by inserting iron and copper filings and sulphur powder into an iron crucible which was made by drilling a 3/32 in. hole into a 3/16 in. iron rod. These were compressed with a tapered iron plug. The latter also served to retain, first the sulphur, and then later the liquid in the compact during the annealing. The iron used was Puron which contained 0.17 pct O by vacuum fusion analysis and about 0.1 pct other elements. The copper contained 0.008 pct Fe and smaller traces of Ni, Si, and Ag. The copper sulphide was made both by subjecting the above copper to sulphur vapors in an evacuated sealed tube at 500°C and by mixing copper and sulphur in the compacts.

Fig. 5 gives the diagrammatic layout of the furnace equipment. The specimens were annealed under a hydrogen atmosphere and quenched into a water stream. Temperatures were measured with chromel-alumel thermocouples within the radiation muffles.

The capillary depression of the two-liquid interface was obtained under a nitrogen atmosphere after initial evacuation. After the copper and copper sulphide had melted, the two capillaries, 1 in. long, were pushed through the two-liquid interface by an iron weight. This iron weight and iron in the bottom of the crucible also served to saturate the liquids with iron. The crucible tube was placed in the furnace in a position so that a minimum amount of "copper" or "copper sulphide" masked the menisci. The liquids were allowed to stand at least 30 min before the X-ray exposure, during which time the crucible was vibrated at intervals so that better assurance of correct meniscus differentials was obtained.

The liquid densities were measured by determining the maximum pressures required to bubble nitrogen through different depths of the liquids, as shown in Fig. 6.

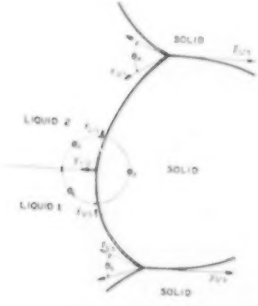
Fig. 1 (left)—Schematic representation of the interfacial energy relationships in a three-phase alloy.

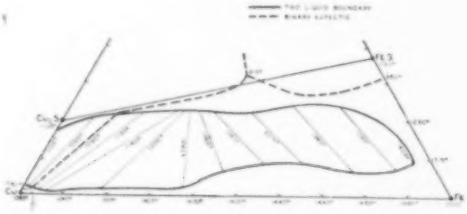
$$\gamma_{S/S} = \frac{\sin\theta_2}{2\sin\theta_3}\,\gamma_{L/L}$$

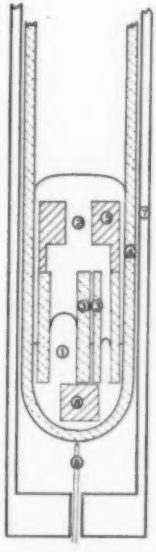
Fig. 2 (center)—Fe-Cu-Cu_2S-FeS system.[11]

Fig. 3 (right)—Capillary tube arrangement for the determination of the energy of the liquid Cu/liquid Cu_2S interface.

1—Liquid Cu
2—Liquid Cu_2S
3—Fused silica tubes
4—Fused silica crucible
5—Iron weight
6—Thermocouple
7—Sillimanite muffle
8—Iron







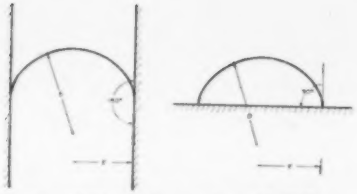


Fig. 4—a (left)—Meniscus surface with 180° contact angle. b (right)—Drop surface with 90° contact angle.

Contact radius, r. Radius of surface curvature, b.

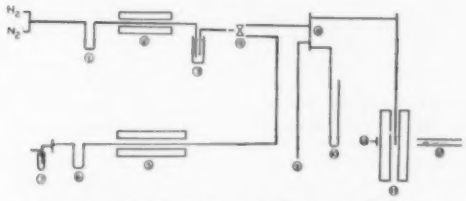


Fig. 5—Diagrammatic layout of laboratory equipment.

1—Drying tube
2—Deoxidation furnace
3—Liquid N_2 trap
4—Two-way stopcock
5—Annealing furnace
6—Drying tube
7—Trap and bubbler
8—Manifold
9—Vacuum pump (mechanical)
10—Hg manometer
11—X-ray furnace
12—220 kv X-rays
13—Film holder

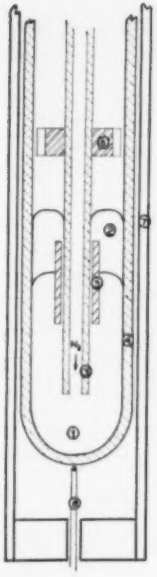


Fig. 6—Sketch of crucible for the determination of liquid densities.

1—Liquid Cu
2—Liquid Cu_2S
3—Fused silica tube
4—Fused silica crucible
5—Iron sleeve
6—Carbon centering block
7—Sillimanite muffle
8—Thermocouple

The radii of the capillaries were used to calculate the radii of curvature of the two-liquid interface at the crown of the menisci. The former were measured as two perpendicular diameters at each end of the 1-in. capillary tube.

Energy of the Two-Liquid Interface

The density determinations required for the calculation of the interfacial energies are presented in Table I. The energies of the interface between liquid copper and liquid copper sulphide at several temperatures are given in Table II. The energies were determined for both iron-saturated and iron-free liquids.

The energy of the interface decreased with increasing temperature over the temperature range examined, as shown in Fig. 7. This decrease would continue to zero near the critical temperature where the two liquids become mutually miscible.[8] Reuleaux[10] showed that this critical temperature is slightly above 1400°C when the two liquids in the Cu-Fe-S system are saturated with iron, as indicated in Fig. 2. An extrapolation of the interfacial energies between the iron-saturated liquids to zero at the critical temperatures is in accordance with the above expectations. The interfacial energy of the iron-free liquids decreased less with increased temperatures than did the energy between the iron-saturated liquids.

Intergranular Energy of γ Iron

The observed dihedral angles, from which the relative energies of the interfaces in the three-phase Fe-Cu-Cu_2S alloy were determined, are shown in Fig. 8 as frequency distribution plots. In addition to the plots for the five angles to the nearest 10°, Fig. 8A to 8E, the dihedral angles observed for Fe vs. Cu/Cu_2S were plotted to the nearest 2°. While the resulting accuracy was not increased propor-

Table I. Density Determinations

Test	Liquid	Saturated With	Temperature, °C	Density, G per Cm^3
202	Copper	Sulphur	1115	7.8_5
	Copper	Sulphur	1158	7.7_6
	Copper	Sulphur	1208	7.7_1
204	Copper sulphide	Copper	1125	5.3_7
	Copper sulphide	Copper	1126	5.4_2
	Copper sulphide	Copper	1158	5.3_7
	Copper sulphide	Copper	1207	5.3_6
203	Copper	Iron and sulphur	1125	8.0_6
	Copper	Iron and sulphur	1125	8.1_1
	Copper	Iron and sulphur	1154	8.0_1
	Copper	Iron and sulphur	1209	7.9_9
205	Copper sulphide	Iron and copper	1154	5.0_5
	Copper sulphide	Iron and copper	1153	5.1_0
	Copper sulphide	Iron and copper	1206	5.0_6
	Copper sulphide	Iron and copper	1119	5.1_2

Table II. Liquid Copper-Liquid Copper Sulphide Interfacial Energy Determinations

Test	Temperature, °C	R, Cm	r, Cm	ΔH,* Cm	a,† Cm^2	a^2 (Corrected),† Cm^2	γ Ergs per Cm^2
Saturated With Iron							
207E	1162	0.323	0.092	0.51_4	0.066_1	0.60_9	86
207F	1124	0.323	0.092	0.57	0.073_8	0.68_4	96
207G	1129	0.323	0.092	0.57	0.072_6	0.668_6	96
207H	1208	0.323	0.092	0.42_7	0.054_9	0.050_2	71
207J	1209	0.323	0.092	0.42_7	$0.05 4_9$	0.050_2	71
206A	1154	0.333	0.092	0.52_3	0.060_9	0.061_2	$87._5$
206B	1154	0.333	0.092	0.54_8	0.069	0.063_1	90
186B	1153	0.156	0.112	0.16_6	0.064_6	0.060_2	86
212A	1134	0.167	0.108	0.24_7	0.070_2	0.065_5	95
212B	1124	0.167	0.108	0.23_2	0.067_6	0.062_7	91
212C	1186	0.167	0.108	0.20_4	0.030	0.054	77
Iron Free							
210A	1131	0.230	0.112	0.38	0.082_5	0.076_{11}	90
210C	1131	0.230	0.112	0.38	0.082_5	0.076_{11}	90
210D	1159	0.230	0.112	0.36_4	0.079_5	0.073_7	87
210E	1216	0.230	0.112	0.33	0.072_8	0.066_4	$76._5$

* Corrected for the divergence of X-rays.
† Corrected for meniscus shapes.

Table III. Dihedral Angles in the Fe-Cu-Cu_2S Alloy at 1105°C

Dihedral Angle	Observed	Calculated from Eq 1
Cu vs. Fe/Cu_2S	95°	77°
Cu_2S vs. Fe/Cu	100°	115°
Fe vs. Cu/Cu_2S	168°	
Cu_2S vs. Fe/Fe	50°	
Cu_2S vs. Fe/Fe	25°	

Table IV. Interfacial Energies of the Fe-Cu-Cu_2S Alloy at 1105°C

Interface	Energy, Ergs per Cm^2
Liquid copper/liquid copper sulphide	100
Liquid copper/γ iron	430
Liquid copper sulphide/γ iron	470
γ iron/γ iron	850

tionally in the latter case, the smaller overall variation in observed angles did permit a closer estimation of the true dihedral angle. This was desirable because it is a large angle and its sine function is used in the calculation of the relative interfacial energies.

There is evidence that the two-liquid interface moved on solidification. On the basis of the relative interfacial energies of the two iron-liquid interfaces as determined from the dihedral angles of the two liquids between iron grains, the Cu_2S vs. Fe/Cu dihedral angle decreased about 15°, as given in Table III. The Cu vs. Fe/Cu_2S angle increased by a similar amount. This movement may be associated with the lower specific volume of the solid, since the interface moved toward the copper sulphide which solidified first. It would not be expected that all of the two-liquid interfaces would be moved to give identical solid interfacial angles. The breadth of the frequency distribution curves, shown in Fig. 8C and 8D, supports this expectation.

Inasmuch as there was an apparent movement of the two-liquid interface during solidification, the relative and calculated dihedral energies were determined on the basis of the angles between interfaces involving a solid. These energies for the alloy of γ iron, liquid copper, and liquid copper sulphide at 1105°C are given in Table IV. It may be pointed out, however, that since the interfacial angles involving the two-liquid interface were near 90°, and their sine function was concerned, errors corrected by this precaution were relatively small. For example, the energy of the liquid copper/γ-iron interface would have been 470 ergs per cm^2 instead of 430 ergs per cm^2.

An effort was made to determine the intergranular energy of iron at higher temperatures. However, at temperatures much above 1090°C, where the two liquids form, iron precipitated from the liquid copper sulphide onto the iron interface during quenching to obliterate partially the original iron/copper sulphide interface. This happened even with the most severe quench. Consequently, the relative interfacial energies were not estimated for the higher temperatures.

The accuracies of the calculated interfacial energies in Table IV are limited chiefly by the accuracy in the measurement of the Fe vs. Cu/Cu_2S dihedral angle. A 15 pct possible error exists with a 2° error in that angle. An approximate check on the above value of 850 ergs per cm^2 for the intergranular energy of γ iron at 1105°C may be obtained from Bailey and Watkins'[8] determination of the copper grain boundary energy. From the dihedral angle measurements, the relative energies of the iron and copper grain boundaries in iron-copper alloys at

Table V. Dihedral Angles of Cu-Fe Alloys

Test	Temperature, °C	Dihedral Angle	Observed
281	1000	Cu vs. γ/γ	70°
281	1000	γ vs. Cu/Cu	110°
299	825	Cu vs. α/α	95°
299	825	α vs. Cu/Cu	110°
237	1160	Liquid vs. γ/γ	30°
238	1220	Liquid vs. γ/γ	30°

Table VI. Interfacial Energies of Cu-Fe Alloys

Temperature, °C	Interface	Relative Energy*
1000	γ/γ	1.00
1000	γ/Cu	0.61
1000	Cu/Cu	0.70
825	Cu/Cu	0.7
825	α/Cu	0.6
825	α/α	0.85
1160	Liquid/γ	0.51;
1220	Liquid/γ	0.51;

* Reference value.

Table VII. Relative Interfacial Energies of α-γ Sulphide Alloy

Interface	Course of Calculation*	Relative Value†
γ iron/γ iron		1.0
	1, 3, 2	1.02
	1, 3, 4, 5, 2	0.98
	2, 3, 1	0.99
	2, 5, 4, 3, 1	1.03
	Avg	1.00
γ iron/α iron	2	0.71
	2, 5, 4, 3	0.74
	1, 3	0.72
	1, 3, 4, 5	0.69
	Avg	0.72
α iron/α iron	1, 3, 4	0.89
	2, 5	0.91
	1, 3, 5	0.92
	2, 3, 4	0.86
	Avg	0.90
Sulphide liquid/γ iron	1	0.65
	2, 3	0.64
	2, 5, 4, 3	0.67
	Avg	0.65
Sulphide liquid/α iron	1, 3	0.69
	1, 3, 5, 4	0.72
	2, 5, 4	0.71
	2, 3	0.67
	Avg	0.70

* See Fig. 9.
† Reference value.

Table VIII. Relative Interfacial Energies of Liquid Sulphide/Iron Interfaces

Test	Temperature, °C	Dihedral Angle Liquid vs. Fe/Fe	Liquid-Iron Interfacial Energy Fe/Fe = 1.0	Fe Content of Liquid,[17] Pct
260	1026	30°	0.51_5	70
256	1198	25°	0.51_5	74
258	1301	0	≤ 0.50	78
277	1325	0	≤ 0.50	80

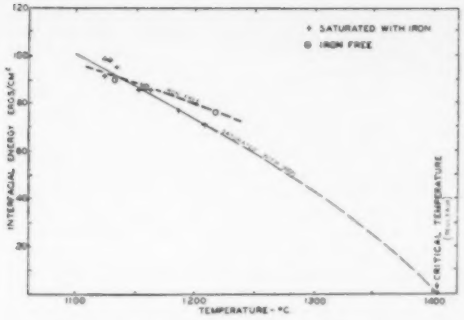


Fig. 7—Energy of the liquid Cu/liquid Cu_2S interface.

1000°C are 1.0 and 0.7 respectively, Tables V and VI. Therefore, using their approximate value of 640 ergs per cm² for the energy of the copper grain boundary, the intergranular energy of copper-saturated iron would be 915 ergs per cm².

Relative Intergranular Energies of α and γ Iron

The above measurements for the intergranular energy of iron were made on copper-saturated γ iron. Alpha iron cannot be in equilibrium with the copper-saturated γ iron,[14] and a liquid pair was not found which was suitable for use in the temperature range of α iron without the addition of ferrite-forming alloying elements. However, if it may be assumed that the energy of the copper grain boundary is somewhat constant with lowering temperatures, the relative intergranular energy of α and γ iron may be determined by annealing copper-iron alloys below their eutectoid temperature. This gives a value for the α-iron grain boundary as 0.85 that of the γ-iron boundary, as shown in Tables V and VI.

A more direct comparison of the energy of the α and γ-iron grain boundaries may be made by measuring the dihedral angles in a duplex, α-γ alloy. This was done by adding 4 pct Si and 0.2 pct C to ingot iron. To give a third phase, 0.26 pct S was added and thus offered a means of checking the relative values.[6] See Fig. 10. Table VII shows these values for the recrystallized alloys at 1150°C. These are calculated from the interfacial angles shown in Fig. 9.

The energy of the α/α boundary is about 0.9 that of the γ/γ boundary. The α/γ boundary energy was less than either the α/α, or the γ/γ boundary energy—about 0.7 of the latter.

The discrepancy appearing in the relative values of the energy of the α/α boundary as determined by the two methods must be attributed, at least in part,

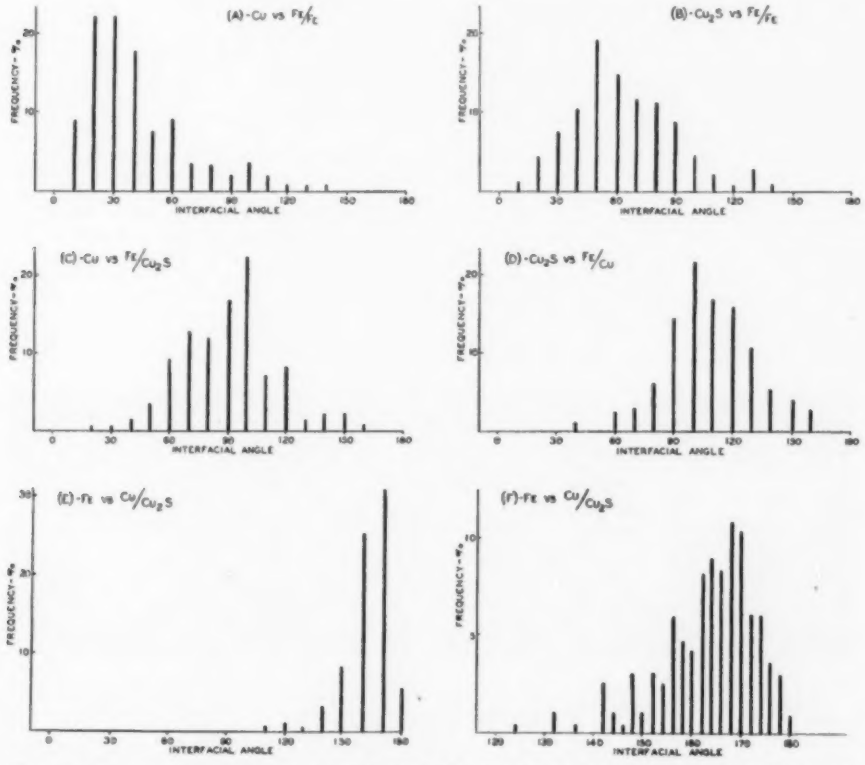


Fig. 8—Test No. 252. Distribution of the observed dihedral angles in the Fe-Cu-Cu_2S alloy. Annealed at 1105°C for 1 hr and quenched.

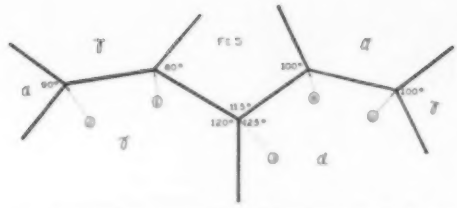


Fig. 9—Schematic representation of interfacial angles in an α-γ-FeS alloy, Fig. 10.

to the differences in compositions of the iron phase in the presence of silicon and copper.

The appearance of the duplex, α-γ alloy, given in Fig. 11, suggests that there is an orientation of the two-phase boundary with lower interfacial energy. On solidification, an alloy of this composition forms chiefly ferrite, but on cooling, austenite forms from part of the ferrite.[16] As indicated in Fig. 11, this proceeds along specific crystal directions. Annealing for extended periods of time does not reduce the interfacial area noticeably. Presumably an increase in energy would be required to move the interface even though a reduction of surface area would be obtained. If the alloy is recrystallized by hot working in the same temperature range, this preferred boundary orientation disappears and a normal two-phase structure is obtained, shown in Fig. 12.

Relative Energies of Iron/Liquid Interfaces

Sulphur-Containing Liquids: The distribution of an iron-sulphur liquid in iron alloys has been of interest to metallurgists. In order to gain some information regarding the effect of interfacial energies upon this distribution, a series of samples, which were quenched from their annealing temperatures, were examined microscopically. The dihedral angles formed between iron grains by liquids containing iron sulphide at several temperatures above the eutectic are given in Table VIII.

The iron used in this case had been remelted under hydrogen to remove essentially all of the oxygen. At 1300°C, the liquid spread between most of the iron grains, as shown in Fig. 13, indicating that the energy of the liquid-iron interface had decreased to one half, or less, of the intergranular energy of iron. Some fewer obvious exceptions are illustrated by Fig. 13 where the observed dihedral angles were still finite. Presumably a slight variation existed in the boundary energies with orientation, and as such, all of the dihedral angles did not become zero at once.

The decrease of the relative energy of the liquid-iron interface with increasing temperature cannot be assigned to the temperature rise alone.[16] The composition of the liquid changes to higher iron contents along the liquidus of the iron-iron sulphide system.[17] In that situation, there is greater similarity between the composition of the two phases so that atoms at the interface require less additional energy by virtue of their position.

The presence of oxygen in the sulphide-containing liquid showed comparatively little effect on the relative liquid/iron interfacial energy at temperatures below 1200°C, as given in Table IX. However, at 1300°C, the dihedral angle did not drop to zero as it did with the oxygen-free liquid, shown in Fig. 15. The explanation of this difference may lie with the liquidus relationships in the Fe-FeS-FeO system. On the basis of Vogel and Fulling's[18] and Gurry, Darken and Anderson's[19] work, the liquidus isotherms for this system are shown in Fig. 14. The oxygen-free liquid is richer in iron than the oxygen-containing liquid at 1300°C. This difference is not so marked at 1200°C or lower.

Table IX. Relative Interfacial Energies of Liquid Sulphide-Oxide/Iron Interfaces

Test	Temperature, °C	Dihedral Angle Liquid vs. Fe/Fe	Liquid-Iron Interfacial Energy Fe/Fe = 1.0	FeS/FeO (Approx.)	Fe Content of Liquid,* Pct
73	1000	35°	0.53_5	10/1	69
62	1150	25°	0.51_2	10/1	71
104	1215	20°	0.50_7	10/1	73
150	1300	15°	0.50_4	10/1	75
276	1325	25°	0.51_2	8/2	73

* Fig. 14.

A phase consisting of equimolecular amounts of FeS and FeTe may be liquid in the presence of α iron. Thus, a general comparison of the relative interfacial energies, liquid/solid and solid/solid may be made when the solid is either α or γ iron. In both

Fig. 10—Test No. 295. Three-phase iron-silicon-carbon-sulphur steel.

5.10 pct Si, 0.22 pct C, 0.26 pct S. Hand forged at 1050°C to 50 pct reduction. Annealed at 1150°C for 30 min and quenched. Nital etch. X500. Area reduced approximately 33 pct for reproduction.

Fig. 11—Test No. 283. α-γ steel.

3.82 pct Si, 0.16 pct C. Annealed at 1003°C for 48 hr and quenched. Nital etch. X500. Area reduced approximately 33 pct for reproduction.

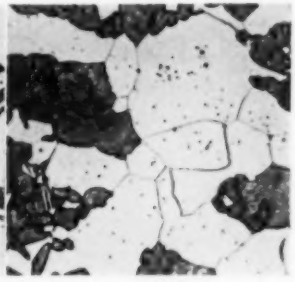


Fig. 12—Test No. 287. α-γ steel, recrystallized.

Same alloy as Test No. 283. Forged to 20 pct cross-section, annealed at 1000°C for 30 min and quenched. Nital etch. X500. Area reduced approximately 33 pct for reproduction.

cases the liquid/iron interfacial energies are similar and slightly over one half of the iron/iron energy, see Table X. A direct comparison may not be made between the intergranular energy of the α and γ iron from this data, however, because the liquid/solid interfaces are not identical in each case.

Some alloying elements appear to have an effect upon the shape of the sulphide liquids between the iron grains. The sulphide liquid in the high silicon α-γ alloy described previously, Fig. 10, showed relatively high interfacial energies with the two iron phases. The energies were approximately two thirds that of the α/α or γ/γ intergranular energy. Likewise, Sims[20] found microstructures which might be interpreted to result from higher liquid/iron interfacial energies in steels which were silicon-killed.

Metal Liquids: Liquid copper will infiltrate into iron compacts[21] and will form a relatively small dihedral angle between iron grains. These features have been assigned to the interfacial energy relationships. The solubility of iron in copper does not increase markedly under 1250°C.[14] Consequently, it may be anticipated that the energy of the liquid-copper/γ-iron interface is relatively constant below that temperature. This was observed to be true on the basis of dihedral angles which were formed, Tables V and VI.

Table X. Relative Interfacial Energies of Liquid Sulphide-Telluride*/Iron Interfaces

Test	Temperature, °C	Dihedral Angle Liquid vs. Fe/Fe	Liquid/Iron Interfacial Energy
144	890	20°	0.50_γ
265	1028	25°	0.51_γ

*S = Te (atomic percent)

An addition of silver to liquid copper materially increases the liquid/iron interfacial energy until, in silver-rich liquids, the dihedral angle is near 180°. Likewise liquid lead, bismuth, and cadmium form dihedral angles between iron grains which are near 180°, indicating that the liquid/iron interfacial energy is relatively large. Iron is essentially insoluble in all of these liquids.

The difference in energies of the copper/iron and silver/iron interfaces cause the contact angles which these two liquids make with iron surfaces to differ. Molten copper has a 0° contact angle against iron in hydrogen. Molten silver has a contact angle of approximately 90°. From these relationships, it may be assumed that the surface energy of γ iron is approximately the same as the iron/silver interfacial energy and equal to, or greater than, the sum† of the iron/copper interfacial energy and the surface energy of liquid copper.†

Movement of Iron Interfaces

Smith[4] suggests three possible methods by which an interface between two phases may move to approach an equilibrium shape. 1—The atoms of one phase may diffuse through the other phase from positions of high surface energy to positions of lower surface energy. 2—This diffusion may proceed along the interface rather than through an adjacent phase. 3—The interfacial energies are sufficient to deform plastically the materials into shapes of minimum surface energies.

† By making the broad assumption that iron does not alter Sauerwald's[22] value of 1120 ergs per cm² for the surface energy of molten copper, a rough estimate for the minimum value for the surface energy of copper-saturated iron would be 1550 ergs per cm².

Fig. 13—Test No. 277. Iron sulphide liquid in iron oxide-free iron.

Annealed at 1325°C for 30 min and quenched. X500. Area reduced approximately 33 pct for reproduction.

The diffusion processes appear to be the more significant methods of interfacial movement in the liquid-iron systems studied. For example, the energies associated with the liquid-silver/iron or liquid-cadmium/iron interface are relatively high as shown by the large dihedral angles they form between iron grains. Yet with these higher energies, the silver/iron interfaces did not readily conform to equilibrium shapes, as shown in Fig. 16. Likewise, angular iron grains in liquid cadmium did not spheroidize by plastic deformation. At the same temperature, the interface between iron and an iron sulphide liquid conformed readily to the interfacial forces although the energy of the interface was relatively low, as shown in Fig. 17. The iron must be dissolved and reprecipitated through the liquid phase or along the liquid interface to move the interface.

The grain boundaries in iron appeared to be influenced by the presence of iron oxide inclusions, Fig. 18. Three times as many inclusions were observed on the convex side of the α-iron boundaries as on the concave side, as given in Table XI. The convex side would be behind the grain boundary if the grain boundaries may be assumed to move toward their center of curvatures.[5] Presumably the grain boundary moved forward more rapidly when it first came in contact with the inclusion, because

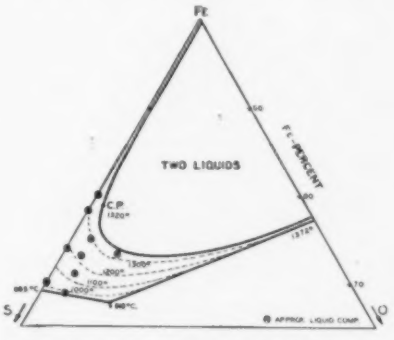


Fig. 14—Liquidus surface of the Fe-FeS-FeO system.[15, 19]

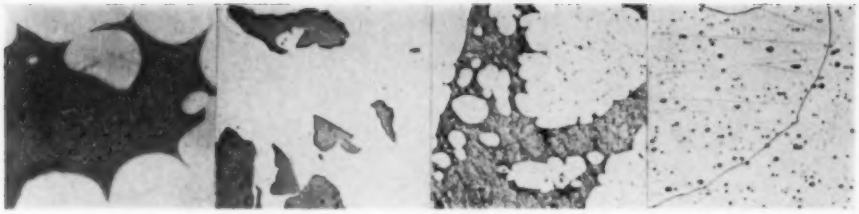


Fig. 15—Test No. 276. Iron sulphide-iron oxide liquid in iron.

Sulphur/oxygen = 8/2. Annealed at 1325°C for 30 min and quenched. X300. Area reduced approximately 33 pct for reproduction.

Fig. 16—Test No. 280. Liquid silver and γ-iron interfaces.

Annealed at 1000°C for 30 min and quenched. X200. Area reduced approximately 33 pct for reproduction.

Fig. 17—Test No. 75. Liquid sulphide and γ-iron interfaces.

Annealed at 1000°C for 30 min and quenched. X200. Area reduced approximately 33 pct for reproduction.

Fig. 18—Test No. 109. Boundary between α-iron grains which contain iron oxide inclusions.

Iron oxide = 1.0 vol pct. Wire drawn and annealed at 885°C for 10 hr. X125. Area reduced approximately 33 pct for reproduction.

the curvature of the surface became much sharper as the boundary assumed a position essentially normal to the inclusion surface. When the boundary, as a whole, moved beyond the inclusion, the curvature in the immediate vicinity of the inclusion was first decreased and then reversed. As such, the boundary was halted locally, leaving the majority of the grain boundary inclusions in the observed positions. The austenitic grain growth inhibition in steels, which is attributed to alumina inclusions,[23] quite possibly results from this type of boundary retention. There the inclusion size is markedly smaller. As a result the grain growth is controlled by a relatively small inclusion volume.[24]

Summary

The energy of the γ-iron grain boundary was determined, and the microstructures of iron containing several metallic and nonmetallic phases were examined with an attempt to interpret some of the observed structures in terms of the interfacial energy relationships.

To determine the energy of the γ-iron grain boundary, the interfacial energy between liquid copper and liquid copper sulphide was measured from the differential depression of their interface in two capillary tubes of unequal radii. The liquid copper/γ-iron, liquid copper sulphide/γ-iron, and γ-iron/γ-iron interfacial boundaries were then calculated from the dihedral angles—Fe vs. Cu/Cu_2S, Cu vs. Fe/Fe, and Cu_2S vs. Fe/Fe.

In addition to the differential depression of the menisci, which was determined by radiography, the densities of the two liquids, and the radii of curvatures of the menisci were required for the calculation of the energy of the two-liquid interface. The densities were measured from the pressures required to bubble nitrogen through the liquids. The radii of interfacial curvatures were calculated from the capillary radii by using Sugden's treatment of Bashforth and Adams' tables. The dihedral angles used were those most frequently observed in the microsection of a quenched sample.

The energy of the iron-saturated, two-liquid interface is 100 ergs per cm^2 at 1105°C, dropping to approximately 70 ergs per cm^2 at 1200°C. This decrease may be extrapolated to zero near the critical temperature slightly above 1400°C. At 1105°C, the following interfacial energies involving iron were established: Liquid copper/liquid copper sulphide, saturated with Fe, 100 ergs per cm^2; liquid copper/γ iron, 430 ergs per cm^2; liquid copper sulphide/γ iron, 470 ergs per cm^2; γ iron/γ iron, saturated with Cu and S, 850 ergs per cm^2.

In a duplex, α-γ, iron-silicon alloy the energy of the α-iron grain boundary was observed to be 0.9 that of the γ-iron boundary. In an iron-copper alloy, the above value was 0.85. In the former alloy, the energy of the α/γ boundary was 0.7 that of the γ-iron boundary.

The interfacial energy between γ iron and a sulphide liquid was a little greater than 0.5 that of the γ-iron/γ-iron energy at 1000° to 1200°C. Above 1200°C, the liquid-iron interfacial energy dropped to less than 0.5. When oxygen was present with sulphur in the liquid this relative energy did not drop to less than 0.5. Thus a noticeable difference in microstructure resulted because the liquid spread less extensively between the iron grains in the latter case.

Evidence is given showing that the movement of the solid/liquid interfaces in compliance with the interfacial energy results from diffusion, either through the liquid or along the phase boundary, and not from the plastic deformation of the solid.

Some evidence is given to show the manner by which inclusions in iron act as grain growth inhibitors.

Table XI. Location of Inclusions on Grain Boundaries

Location	Number Observed
Convex side (Fig. 24)	227
Concave side	74
Approximately centered	211
Straight boundaries	140

Acknowledgments

A large share of the work required for this study was done as an employee of Carnegie-Illinois Steel Corp. This was made possible through the efforts of E. W. Pierce and B. R. Queneau of South Works. All of this is gratefully appreciated. The generous guidance of C. S. Smith and the stimulating discussions with him and others of the Institute for the Study of Metals were indispensable. The facilities of both the Institute and South Works were made available.

References

[1] F. Bashforth and J. C. Adams: An Attempt to Test the Theories of Capillary Action. (1883). Cambridge University Press.

[2] J. Plateau: Statique Experimentale et Theorique des Liquides soumis aux seules Forces moleculaires. (1873). Paris. Gauthier-Villars.

[3] F. Neumann: Theorie der Capillaritat. p. 162. (1894). Leipzig. B. G. Teubner.

[4] C. S. Smith: Grains, Phases, and Interfaces: An Interpretation of Microstructure. Trans. AIME. (1948), **175**, pp. 15-51; METALS TECHNOLOGY (June 1948) TP 2387 E.

[5] N. K. Adam: The Physics and Chemistry of Surfaces. 3rd Ed. (1941). London. Oxford University Press.

[6] H. Udin, A. J. Shaler, and J. Wulff: The Surface Tension of Solid Copper. *Trans.* AIME (1949) **185**, pp. 186-190; JOURNAL OF METALS (Feb. 1949) TP 2530 E.

[7] B. Berggren: Uber eine Methode zur Bestimmung der Oberflachenspannung Amorpher Korpen. *Ann. d. Physik* (1914), **44**, Ser. 4, p. 61.

[8] G. L. C. Bailey and H. C. Watkins: Surface Energies in the System Solid Copper-Molten Lead. *Proc.* Phys. Soc. (London) (1950) **63B**, p. 350.

[9] D. Harker and E. Parker: Grain Shape and Grain Growth. *Trans.* ASM. (1945), **34**, pp. 156-195.

[10] J. C. Fisher: Measurement of Interfacial Tensions. *Trans.* AIME (1948) **175**, p. 906; METALS TECHNOLOGY (June 1948) TN 1E.

[11] C. G. Dunn and F. Lionetti: The Effect of Orientation Difference on Grain Bcundary Energies. *Trans.* AIME (1949) **185**, pp. 125-132; METALS TECHNOLOGY (Feb. 1949) TP 2517 E.

[12] O. Reuleaux: Reaktionen und Gleichgewichte im System Cu-Fe-S mit besonder Berucksichtigung des Kupfersteine. *Metall und Erz* (1927) **24**, pp. 99-111; *Ibid.*, pp. 129-134.

[13] S. Sugden: Determination of Surface Tension from the Rise in Capillary Tubes. *Journal* Amer. Chem. Soc. (1925) **47**, pp. 60-64.

[14] B. N. Daniloff: Cu-Fe Copper Iron. *Metals Handbook*, (Cleveland: American Society for Metals, 1948), p. 1196.

[15] E. S. Greiner, J. S. Marsh, and B. Stoughton: The Alloys of Iron and Silicon. p. 141. (1933) New York. McGraw-Hill Book Co.

[16] K. K. Ikeuye and C. S. Smith: Studies of Interfacial Energies in Some Aluminum and Copper Alloys. *Trans.* AIME (1949) **185**, pp. 762-768; JOURNAL OF METALS (Oct. 1949) TP 2691 E.

[17] J. Chipman: Fe-S Iron-Sulphur. *Metals Handbook*, (Cleveland: American Society for Metals, 1948), p. 1215.

[18] R. Vogel, and W. Fulling: The System Fe-FeS-FeO. *Fostkrift J. Arvid Hedvall* (1948) pp. 577-610.

[19] R. W. Gurry, L. S. Darken, and O. Anderson: The Melting Diagrams of the System Iron Oxide-Iron Sulphide. U. S. Steel Research Lab. (1940) Unpublished.

[20] C. E. Sims, H. A. Saller, and F. W. Boulger: Relative Deoxidizing Power of Some Deoxidizers for Steel. *Trans.* AIME (1949) **185**, pp. 814-825; JOURNAL OF METALS (Nov. 1949) TP 2557 C.

[21] P. Schwartzkopf: Infiltration of Powder Metal Compacts with Liquid Metal. *Metal Progress* (1950) **57**, pp. 64-68.

[22] W. Krause, F. Sauerwald, and M. Michalke: Die Oberflachspannung Geschmelzener Metalle und Legoirungen. *Ztsch. f. Inor. Chem.* (1929) **181**, pp. 353-371.

[23] G. Derge, A. R. Kommel, and R. F. Mehl: Some Factors Influencing Austenitic Grain Size in High Purity Steel. *Trans.* ASM (1938) **26**, pp. 153-172.

[24] C. Zener: Communication to C. S. Smith. "Grains, Phases, and Interfaces." *op. cit.*

Technical Note

Precipitation and Diffuse Scattering in an Fe-Mo-Co Alloy

by A. H. Geisler and F. E. Steigert

THE permanent magnet alloy comol, which contains 17 pct Mo, 12 pct Co, balance Fe, exhibits a precipitation reaction analogous to that at the iron end of the binary Fe-Mo system. The equilibrium precipitate, (P_s), has a structure isomorphous with Fe_7Mo_6 which is rhombohedral with parameters $a = 8.97$A and $\alpha = 30°38.6'$ according to the work of Arnfelt and Westgren.[1] In the ternary alloy the parameters are $a = 8.87$A and $\alpha = 31°0.5'$. Oscillating crystal patterns of a single matrix crystal, M, in which P_s was precipitated by slow cooling from 1300°C, showed that the orientation relationship of the two lattices is as follows:

$$(1\bar{1}0)_{P_s} \;//\; (110)_M$$

$$(11\bar{1})_{P_s} \;//\; (1\bar{1}0)_M$$

There are crystallites of P_s in 12 different orientations in a single crystal of the parent solid solution. Microscopic examination shows that the crystallites are generally plate-like with their lateral dimensions parallel to {110} matrix planes.

When precipitation in a supersaturated alloy quenched from 1300°C progressed isothermally at temperatures between 600° to 800°C, the evolution of the P_s structure could be traced. Diffuse diffraction effects in Laue patterns provided early evidence of the precipitation process. Analyses of these by a previously described technique[2] showed that they corresponded to rod-like elements parallel to <110> matrix directions in reciprocal space. With further aging to promote growth of the precipitate, the rod-like elements contracted to points in reciprocal space for normal Bragg reflection from the precipitate as shown by the left diagram in Fig. 1. Thus the diffuse scattering was attributed to the small thickness of the plate-like particles which was inadequate for sharp diffraction. When the precipitate particles were first thick enough to give normal diffraction their structure was different from that of the equilibrium precipitate, P_s. The first structure, P_1, presumably is a coherent transition struc-

A. H. GEISLER, Member AIME, and F. E. STEIGERT are associated with the Research Laboratory, General Electric Co., Schenectady.

TN 69E. Manuscript, Nov. 1, 1950.

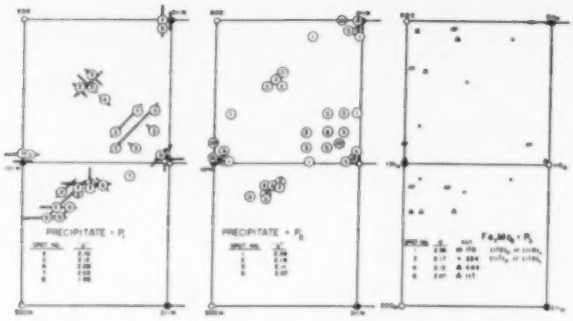


Fig. 1—Reciprocal lattice plots of reflections for the precipitates in comol projected on to the zero layer plane of the parent matrix crystal.

ture, for some of the rods pass through the (101) type points for the matrix showing that a precipitate reflection coincides with the (101) reflections and there are planes in P_1 which have the same spacing as $d_{101\,\alpha}$. Spacings of other planes in P_1 are listed in Table I. Magnetic and mechanical hardening occur during the formation of P_1.

The coherent precipitate, P_1, subsequently transforms into a second structure, P_2, with interplanar spacings that resemble somewhat those of the σ-FeMo phase[2] as shown by the comparison of lines for σ-FeMo with those for specimens aged 18 hr at 700°C, or air cooled from 1300°C in Table I. There are certain similarities of the precipitates P_1 and P_2 which suggest that the second could form by simple readjustments of the first. Reflections Nos. 2 and 5 are common to the two. The structures are differentiated, however, by the slight splitting of the No. 5 reflection near $(011)_\alpha$ in the center diagram of Fig. 1 and by the absence of the two strong reflections Nos. 1 and 6 near the $(011)_\alpha$ type reflections in Fig. 1. On the other hand, these two reflections for P_2 agree with the $(1\bar{1}0)$ and $(11\bar{1})$ reflections for Fe_2Mo_3, the equilibrium precipitate, P_3, at the right in Fig. 1. The second precipitate, however, is differentiated from P_2 by the presence for the former of the No. 5 reflection and the absence of the No. 3 reflections. The equilibrium precipitate, Fe_2Mo_3, forms during aging at the higher temperatures either isothermally or during slow cooling.

A proposed crystallographic mechanism of precipitation in this alloy awaits the solutions of the coherent structure and the sigma phase.

References

[1] H. Arnfelt and A. Westgren: *Ann. Jernkontorets* (1935) **119**, p. 185.

[2] A. H. Geisler and J. K. Hill: *Acta Crystallographica* (1948) **1**, p. 238.

[3] H. J. Goldschmidt: *Research* (1949) **2**, p. 343.

Table I. Interplanar Spacings for Precipitates in Comol

Line No.	Precipitate = P_1	Precipitate = P_2				Precipitate = P_3				
	1 Hr, 700°	18 Hr, 700°	Air Cooled	σ Fe-Mo	Intensities*	18 Hr, 800°	Slow Cooled	Fe_2Mo_3	Intensities*	hkl
1		2.37	2.36	2.35	W	2.37	2.36	2.37	VS	$(1\bar{1}0)$
2	2.19	2.19	2.19	2.21	VS					
3						2.17	2.17	2.17	S	(334)
4							2.13	2.14	M	(444)
5	2.12	2.12	2.11	2.13	M					
6	2.08		2.07	2.08	M	2.08	2.07	2.08	M	$(11\bar{1})$
7	2.02			2.04	S			2.03	S	(443)
8	1.98		1.98	1.99	VS	1.98				
9				1.93	M		1.95	1.95	M	(220)
10				1.90	VW		1.90	1.91	M	(113)
11				1.82	VW		1.82	1.83	W	(234)
12						1.80	1.78	1.79	W	(331)
13							1.73	1.73	W	(224)
14			1.37	1.37	M		1.37	1.35	M	$(1\bar{3}1)$
15						1.32	1.33	1.33	S	(235)
16		1.31	1.31	1.30	S		1.30	1.31	M	(114)
17							1.290	1.297	M	(542)
18	1.283					1.286	1.285			
19		1.274	1.276	1.28	VS			1.276	W	(406)
20	1.257	1.256	1.256	1.246	W	1.251				
21			1.233				1.233	1.237	VW	(225)
22				1.220	M	1.225	1.217	1.227	VW	(643)
23		1.188	1.185	1.177	M	1.187	1.184	1.191	S	(220)
24		1.091	1.082	1.100	M	1.090	1.087	1.092	M	(686)
25				1.068	VS	1.043	1.040	1.045	S	(541)
26				1.035	VS		1.034	1.031	S	(632)

* VS—very strong. S—strong. M—medium. W—weak. VW—very weak.

AIME OFFICERS
Willis M. Peirce, President
Vice Presidents
A. B. Kinzel Philip Kraft R. W. Thomas
J. L. Gillson M. L. Holder
Vice President and Treasurer
Andrew Fletcher

AIME STAFF
E. H. Robie, Secretary
E. J. Kennedy, Jr., Asst. Secy. Ernest Kirkendall, Asst. Secy.
H. N. Appleton, Asst. to Secy. H. A. Maloney, Asst. Treas.

Low Grade Ores, Statistical Control, Increased Steel Output Headline Iron and Steel Conferences

THE Conferences to be held April 2, 3, and 4 by the Blast Furnace, Raw Materials, and Coke Oven Committee and the National Open Hearth Committee will be the 34th of these annual technical meetings. They will consist of a series of technical sessions on iron and steel production; developments in production and operating methods; and consideration of some of the aspects of steel production today in the face of increased demands, diminishing supplies of raw materials, and increased costs of operation.

The Conferences, to be held at the Hotel Statler, Cleveland, will bring together the nation's top authorities in iron and steel plant operation, maintenance, and management, and leaders in such fields as ceramic, refractory, metallurgical, maintenance, and production engineering.

The registration fee will be $5.00 for AIME members and $7.00 for nonmembers. All registrants will receive a copy of the Proceedings when they are compiled. The annual Fellowship Dinner, which will cost $8.00 each, will be held Tuesday evening. A. J. Hopcraft, purchasing agent for Cleveland Worm & Gear Co., Cleveland, will be Toastmaster, and T. F. Patton, vice president and general counsel, Republic Steel Corp. will be Speaker for the dinner.

Through the courtesy of Republic Steel Corp., a tour of some of Republic's facilities in Cleveland has been arranged for Monday. Immediately prior to the tour, there will be a Brunch starting at 11:00 am at the Statler Hotel. From the Brunch, buses will take guests to the plant. To defray transportation costs a charge of $2.00 will be made by the Conference Committees. Reservations must be made in advance.

Preliminary Program of Blast Furnace, Raw Materials, and Coke Oven Conference

Monday, April 2

8:00 am to 9:00 pm
Registration

11:00 am
Brunch, Plant Tour of Republic Steel Corp. (By reservation only).

Tuesday, April 3

8:00 am to 5:00 pm
Registration

9:30 am
General Session:
Opening Remarks. Future Supplies of Iron Ore for United States; Iron Ore Beneficiation; Swedish Iron and Steel Industry.

2:00 pm
Coal and Coke Session:
Coal and Coke Testing; Appraisal of Mineable Coking Coal Reserves in the United States; Low Temperature Coke as a Reactive Carbon.

Agglomerated Materials Session:
New Developments in Sintering Plant Design and Operation (symposium); Physical Testing of Iron Bearing Raw Materials (symposium).

6:30 pm
Reception

7:00 pm
Annual Fellowship Dinner

Preliminary Program of Blast Furnace, Raw Materials, and Coke Oven Conference

Wednesday, April 4

9:00 am to 4:00 pm
Registration

9:30 am
General Blast Furnace Session:

Methods of Statistical Analyses of Blast Furnace Operating Variables; Carbon Hearth Furnaces in United States; Relative Reducibility of Ores and Agglomerated Materials.

12:30 pm
Luncheon and Annual Business Meeting:

All registrations to Blast Furnace, Coke Oven, and Raw Materials Conference are invited to attend this luncheon and business meeting.

2:00 pm
Blast Furnace Operating Session:

Use of High MgO in Slags; Quenching and Digging out a Blast Furnace; Blast Furnace Practice at Houston, Texas.

Preliminary Program of National Open Hearth Conference

Monday, April 2

8:00 am to 9:00 pm
Registration

11:00 am

Brunch, Plant Tour of Republic Steel Corp. (By reservation only).

Tuesday, April 3

8:00 am to 5:00 pm
Registration

9:00 am
Acid and Basic General Session:

McKune Award Paper; Announcements and Reports

10:00 am
Basic Operating Session I:

Methods of Increasing Open Hearth Production; Methods of Increasing Furnace Availability.

Acid Open Hearth Session:

Metallurgical Advantages of Acid Open Hearth Process; Types of Charges and Their Effect on Production Range.

2:00 pm
Refractories and Masonry Session:

Silica Brick Quality; Zebra Roof Construction; Bottom Construction and Bottom Materials; Pouring Pit Refractories.

Quality and Metallurgy Session:

Bath Temperature Control; Factors Affecting Spread in Manganese; Factors Affecting Surface of 0.40 to 0.55 pct Carbon Killed Steel; Production of Mechanically Capped Steel Over 0.15 pct Carbon; Statistical Approach in Control of Open Hearth and Mill Quality; Control of Steel for Deep Drawing Quality.

6:30 pm
Reception

7:00 pm
Annual Fellowship Dinner

Wednesday, April 4

9:00 am to 4:00 pm
Registration

9:30 am
Basic Operating Session II:

Furnace Design for Increased Production

Cold Metal Practice and Basic Foundry:

Linings for Cupolas; High Iron or Ore Charges in Cold Metal Heats; Refractories and Their Performance in Cold Metal Shops; Pouring Refractories in Basic Steel Foundry Practice; Problems Pertaining to Scrap.

2:00 pm
Fuels and Combustion Session:

Flow Patterns in Furnaces; Combination Fuels; Additives to Liquid Fuels to Minimize Deposit; Waste Gas Analyses; Filtered Water and Effect on Maintenance.

Fifth IMD New England Regional Conference

The Fifth Annual AIME New England Regional Conference of the Institute of Metals Div., will be held Apr. 13 and 14, 1951, at the Hotel Taft, New Haven, Conn., according to John Swift, chairman of the conference committee. A series of technical papers, a field trip, and the regular annual dinner have been planned. The technical program includes the following papers on Friday, April 13, at 2:00 pm:

Spectrographic Control Testing in the Brass Mill, A. W. Young, Bridgeport Brass Co., Bridgeport, Conn.

Embrittling Factors in Heat Treated Steels, C. K. Stewart, International Nickel Co., New York.

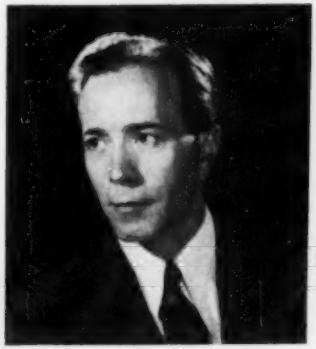
New Gaging Techniques for Metal Rolling Operations, A. S. Burgoyne, Pratt and Whitney Div., Niles-Bement-Pond, West Hartford, Conn.

On Saturday at 9:30 am, there will be a group of papers dealing with advanced experimental techniques and methods of metallurgical observation. This meeting will be conducted as a round table, and the audience will participate. The topics covered at the round table meeting will include: *Phase Contrast Metallurgy*, by Dr. G. L. Kehl, Columbia Univ.; *Electron Metallography, Electron Microscopy, and Diffraction*, by Dr. R. D. Heidenreich of the Bell Telephone Research Laboratory, and *Recent Developments in X-Ray Methods for Texture Determination*, by Dr. Paul Beck, Notre Dame.

A field trip to one of the New Haven industrial plants has been proposed, but plans were not yet completed. This trip, if held, will be on Friday, April 13. The banquet is planned for Friday evening, April 13, and Dr. Bruce Old vice-president of Arthur D. Little, Inc., will be the toastmaster. The speaker will be announced later. John Swift, president of Swift Industrial Chemical Co. is chairman of the Conference; Albert J. Blank, of Chase Brass & Copper Co. is vice-chairman; Michael B. Bever, of Massachusetts Institute of Technology, is secretary; and W. S. Mounce, International Nickel Co., is chairman of the Program Committee.

Personals

ROBERT F. MEHL



BRUCE W. GONSER

BRUCE S. OLD

Robert F. Mehl, director of the metals research laboratory, Carnegie Institute of Technology, Pittsburgh, has accepted the chairmanship of the newly-established Metallurgical Advisory Board of the National Research Council.

Bruce W. Gonser has been appointed to the newly created position of assistant director, Battelle Memorial Institute, Columbus, to work on the technology of the less common metals. Mr. Gonser will guide development in up-to-now unexplored fields of metallurgy and chemistry of the metals. He will continue to direct research in nonferrous metallurgy.

Bruce S. Old has been elected vice-president of Arthur D. Little, Inc., Cambridge, Mass. Mr. Old has been with the company since 1946 in charge of process metallurgy and has been a director since 1949. He recently resigned as part-time consultant to the Atomic Energy Commission, where he was chief of the metallurgy and materials branch, div. of research.

Wilton Melhorn has been named assistant professor of metallurgical engineering at the University of Cincinnati, Cincinnati. Mr. Melhorn is doing graduate work toward a Ph.D. degree.

Bernard O. Brouk is sales engineer for the American Brake Shoe Co., national bearing div., St. Louis. He is also a member of the board of directors for the Precast Slab & Tile Co., St. Louis.

James H. Robins, president of the American Pulley Co. has been made a vice-president of the Franklin Institute, Philadelphia.

John G. Munson has retired as vice-president, raw materials, U. S. Steel Corp. of Delaware. Mr. Munson will serve the company in an advisory capacity.

M. G. McGrath, formerly metallurgical engineer with the U. S. Atomic Energy Commission has become vice-president of the Vitro Chemical Co., Salt Lake City.

Robert P. Lawrence is now development engineer for National Lead Co., titanium alloy mfg. div., New York.

Allen W. Pinger has resigned his position of chief geologist with the New Jersey Zinc Co., Franklin, N. J. He is now associated with the New Jersey Exploration Co., Salt Lake City and is also doing private consulting work.

B. Douglas Weaver is now employed as chief chemist of the Algoma Steel Corp., Ltd., Sault Ste. Marie, Ontario.

James Crowther has been made chief metallurgist of James Booth & Co., Birmingham, England. He had been research metallurgist for the same company.

Griffith Williams, Jr., process engineer for the Bridgeport Brass Co., has been transferred to the Indianapolis plant. He was formerly located in New York.

Norman W. Johnson is now employed by the General Electric Co., Schenectady, in the training program. Mr. Johnson recently graduated from the University of Wisconsin.

S. Frederick Magis, formerly steel works metallurgist for Henry Disston & Sons, Inc., Philadelphia, is now engaged in consulting practice at Wildwood, N. J.

S. R. Maloof has joined the Springfield Armory, Springfield, Mass. as a research metallurgist. He was formerly connected with Sylvania Electric, Inc., Bayside, N. Y.

Jerome Alexander has been made an honorary member of the American Institute of Chemists. Mr. Alexander is a consulting chemist and chemical engineer residing in New York.

Edmund Newton is now chief engineer for the U. S. Ferro Metals Corp., Deming, N. Mex.

F. R. Morral has joined Kaiser Aluminum & Chemical Corp. and will be employed in the metallurgical research div. as head of the X-ray diffraction dept. He was recently associate professor of materials engineering at Syracuse University.

Carl H. Samans, associate director of research, Standard Oil Co., Chicago, has been made representative of the Chicago Section, AIME, to the Chicago Advisory Committee of Engineering Societies Personnel Service, Inc.

Samir Tahir has been appointed lecturer in metallurgy on the faculty of engineering of the University of Ibrahim Pasha The Great, Cairo, Egypt. He was formerly metallurgist at the Egyptian Government Laboratories.

Jesse Oatman Betterton, Jr. has been appointed to the staff of the metallurgical div., Oak Ridge National Laboratory, Oak Ridge. Mr. Betterton is a metallurgical engineer from Oxford University.

Obituaries

Herman G. A. Cowes (Member 1943) died during October 1950. Mr. Cowes was born in Montala, Sweden in 1893 and attended high school there. He attended Techn. College for four years and in 1920 graduated from Techn. University at Stockholm with the degree of Met. Engineer. Following graduation he was employed as a designing engineer by the Surahammars Steelplants. In 1921 he joined the Friedrich-Wilhelms-Hutte openhearth dept., Mulheim/Ruhr, Germany, as superintendent of the department. For two years he was superintendent in charge of blast furnaces and rolling mills for Avesta Steelplants in Sweden. He spent several years in Germany and the United States studying metallurgical methods. In 1927 he returned to Europe and worked for various steel plants in Finland and Sweden. He joined Stromsnas Bruks A.B., Degerfors, Sweden as a consulting engineer working on the design of a new openhearth plant. From 1936 to 1938 he was consulting engineer for steel works in Denmark and Finland. In 1938 he joined Elektrokemisk A. S. in Oslo as metallurgical engineer and was employed by them at the time of his death.

Bert E. Sandell (Member 1931), formerly chief metallurgist and chemist for Stewart Die Casting Div., Stewart-Warner Corp., Chicago, died on Nov. 14, 1950. Mr. Sandell was born on Dec. 18, 1903 in Chicago. In 1922 he joined the Stewart Die Casting Corp. as a chemist. He was made chief chemist in 1925. In 1940 he became chief metallurgist and chemist and held this position until he died.

NECROLOGY

Date Elected	Name	Date of Death
1895	James R. Finlay	Jan. 1, 1951
1921	Royer E. Galbreath	July 8, 1950
1920	Fred S. Gallus	Dec. 16, 1950
1911	A. R. Gordon	Jan. 7, 1951
1931	Karl F. Klein	Jan. 21, 1951
1925	J. P. Leemans	Jan. 13, 1951
1944	Stanley M. McDonald	Dec. 11, 1950
1938	W. M. Myers	Jan. 25, 1951
1915	Clarence B. Osborne	Mar. 15, 1950
1935	William George Polisson	Dec. 12, 1950
1942	Kenneth M. Quickel	Dec. 4, 1950
1896	Edgar Rickard	Jan 21, 1951
1937	Louis Roark	Unknown
1936	Mark A. Smith	Dec. 29, 1950
1909	Donald Steel	Jan. 10, 1951
1947	Henry Thies	Jan. 11, 1951
1902	Francis A. Thomson	Jan. 11, 1951
1924	Alvin D. Whitman	Unknown
1911	Charles C. Whittier	Dec. 18, 1950
1907	Clarence Woods	Nov. 6, 1950

Proposed for Membership

Metals Branch AIME

Total AIME membership on Jan. 31, 1951, was 17,228; in addition 4,613 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Albert J. Phillips, Chairman; George B. Corless, Lloyd C. Gibson, Ivan Given, Plato Malozemoff, R. D. Mollison, John T. Sherman, Harold K. Work. Alternates: Harry P. Croft, Fred W. Hanson, T. D. Jones, Frank A. Ayer, H. W. Hitzrot, and H. K. Masters.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate.

Colorado
Grand Junction—Lennemann, William L. (J)

Connecticut
North Haven—Berwick, John D. (M) (C/S—J-M)

Idaho
Kellogg—Dunn, George W. (M), Lee, Harold E. (M)

Illinois
Alton—Nelson, Alvin H. (J) (C/S—S-J)
Chicago—Dennis, Theodore E. (J), Domagala, Robert F. (J) (C/S—S-J), Farkas, John, Jr. (M) (R. C/S—S-M), Kopchak, Michael C. (J) (C/S—S-J), Loxterman, Henry R. (M), Muller, John J. (J) (C/S—S-J), Schumacher, Henry N. (M)
Collinsville—Langham, Karl, Jr. (J)
Ellyn—Reidy, Edward T. (J)
Evanston—Hall, James MacD. (J)

Indiana
Hammond—Kahl, Wayward H. (M)
Indiana Harbor—Silkiss, Emanuel (J) (C/S—S-J)

Maryland
Baltimore—Chen, Neng K. (J) (C/S—S-J)

Massachusetts
Boston—Backofen, Walter A. (J) (C/S—S-J)
Cambridge—Taylor, Howard F. (M) (C/S—J-M)

Michigan
Detroit—White, Philip R. (J) (R. C/S—S-J)
Kalamazoo—Jackson, Paul L. (J) (C/S—S-J)
Wyandotte—Krainess, Albert M. (J) (C/S—S-J)

Nebraska
Omaha—Reinhardt, John C. (M)

Nevada
Reno—Palmer, Walter S. (M) (R.)

New Jersey
Carteret—Cyke, Freeman H. (M)
Florence—Gruner, Henry M. (M) (R. C/S—S-M)
Mendham—de Neufville, Hugo R. (M)
Metuchen—Moles, Oliver W. (J) (C/S—S-J)
New Milford—Chiaro, Ralph J. (J) (C/S—S-J)

New York
Buffalo—Hart, Charles W. (M) (C/S—A-M)
New York—Hanson, Charles E. (A), Jenness, Leslie G. (M) (R.), McCarthy, Donal E. (J)
Schenectady—Powers, Arthur E. (A) (C/S—S-A)

Ohio
Columbus—Shober, Frederic R. (J)
Jackson—Baumont, Glenn A. (M)
Madeira—Dickens, Albert W. (J) (C/S—S-J)
Toledo—Grott, Gerald J. (J)
Youngstown—Jones, Myron A. (M)

Pennsylvania
Bethlehem—Smith, Andrew P. (M)
Easton—Jones, Robert R. (M) (C/S—J-M)
Latrobe—Harvey, Joseph W. (M)
Philadelphia—Lee, Edward (J) (C/S—S-J), Mills, George J. (J) (C/S—S-J)
Pittsburgh—Beinlich, Justus J. (A), Brezin, Martin (M), Marshall, Clarence T. (A), Morrissey, Herbert A. (J)
Towanda—Pollack, William (J) (C/S—S-J)
West Newton—Younkin, Frank W. (M)

Texas
Houston—Whanger, James R. (J) (C/S—S-J)

Utah
Salt Lake City—Nordby, Norman H. (J)

Virginia
Arlington—Leonard, Wimmer J. (M) (C/S—J-M)

Washington
Spokane—Aust, Karl T. (J)
Tacoma—Sigler, Glenn E. (M) (R. C/S—J-M)

Canada
Quebec—Young, Robert J. (M)

England
Buckinghamshire—Thomas, Gordon J. (M) (R. M)

France
Paris—Durand, Jean L-J (M)

Holland
The Hague—Lopes Cardozo, Alfred (M)

Marianas Islands
Guam—Adams, Charles J. (A) (C/S—S-A)

Mexico
D. F.—Torres, Salvador A. (M)
Monterrey—Graham, John M. (M)

Nova Scotia
Halifax—Hallam, Russell C. (J) (C/S—S-J)

CONFERENCE

April 2 to 4, 1951

The best audience—engineers, superintendents, melters, metallurgists, and executives—of iron, steel, and coke producing companies, will attend a technical meeting to find out what is new in steel, coke, and iron making technology, production methods, and equipment maintenance.

JOURNAL OF METALS will reach every registrant at the meeting in addition to the regular subscribers, carrying the program and advance technical data that will be presented at the meeting.

JOURNAL OF METALS *will carry the only Official Conference Program.*

Reach these men who buy, specify and influence the purchase of your products for these companies. Advertise in the Open Hearth, Blast Furnace, Raw Material, and Coke Oven Conference Special Issue, the April JOURNAL OF METALS.

Write or wire for space reservations now. Plates for advertisements in this issue must be in New York by March 5.

JOURNAL OF METALS

29 West 39th Street • New York 18, N. Y.

New tighter fit

So positive is the fit between seat and plate on this time-tested Brosius-Westling Goggle Valve, that the unit pressure is comparable to that found on flange gaskets in pressure piping. In addition to this new feature, distortion is eliminated due to heavy construction and separation between barrel and frame . . . moreover, manual operation is easy and fast even after long periods of idleness. Numbers of these valves are currently contracted for, yet capacity has not been reached and your inquiry is invited.

BROSIUS DIVISION

Salem - Brosius, Inc., Pittsburgh 15, Pa.

Affiliates: Salem Engineering Division, Salem, Ohio;
Salem Engineering Co., Ltd., Milford nr. Derby, England; Salem Engineering (Canada) Ltd., Toronto, Canada